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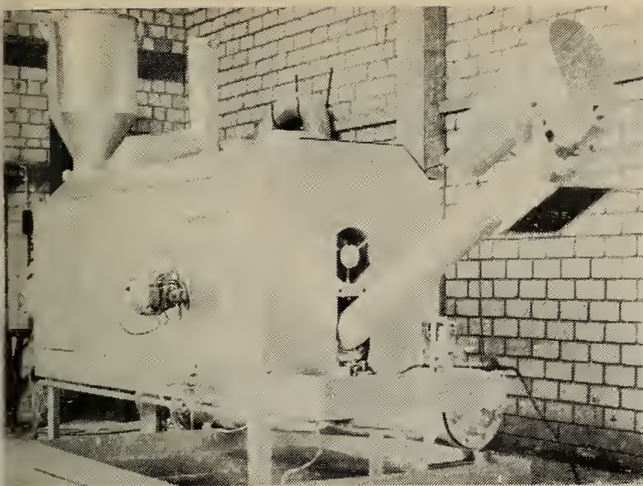

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Resource Recovery and Conservation, 1 (1976) 195

Editorial

This issue is the Proceedings of a symposium, "Energy Recovery from Solid Wastes" held at the University of Maryland, March 13, 14, 1975. It was the fourth in a series entitled, "Science and the Environment" organized by the Washington Academy of Sciences. The symposium was sponsored by the Academy, the Chemical Society of Washington (the Washington, D.C. Section of the American Chemical Society), the National Center for Resource Recovery, Inc. and Committee E-38, Resource Recovery, of the American Society for Testing and Materials.

The utilization of solid wastes as a source of energy, particularly in storable and transportable forms, can supply a portion of a nation's energy needs. This proportion may appear to be small, of the order of say two percent of U.S. daily needs, but even this order of magnitude is large when compared with some other alternative sources which are perhaps less readily available for development and exploitation.

The purpose of the symposium was to review the state of the art and practice of energy recovery from the organic portion of a variety of solid wastes. The emphasis was on processing wastes to some other forms of energy storage, ranging from solid fuel substitutes for coal to gaseous mixtures for fuel to chemicals and proteins. This emphasis did not ignore the direct burning of wastes to raise steam, which is less common in the U.S. than in Europe and Japan. However, the current research interest in the U.S. (and elsewhere) is toward fuels (and other products) prepared to a specification, rather than the utilization of unprocessed mixed wastes in an incinerator. Energy conservation possibly accruing from utilization of recovered materials (e.g., metals, glass, paper and plastics) was not addressed.

This proceedings is simultaneously published as an issue of *Resource Recovery and Conservation* and of the *Journal of the Washington Academy of Sciences.* The editors wish to thank Dr. Richard H. Foote, editor of the *Journal* for his assistance. The three editors thank the authors and organizers for making the symposium possible.

J.G.A.
H.A.

Resource Recovery and Conservation, 1 (1976) 197—206

THE MARKETS FOR AND THE ECONOMICS OF HEAT ENERGY FROM SOLID WASTE INCINERATION*

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(Received 24th March, 1975)

ABSTRACT

This study reviews the disposal and composition of solid waste with respect to its material and energy resources. It evaluates the economics of front-end materials resource recovery and the fluctuating markets for specific components, the energy extraction by conventional incineration, and steam production not only for process needs but also for coolant and/or heating. It touches briefly on energy recovery in the form of off-gas and liquids from pyrolyzers, shredding to provide "fluff", and pelletizing.

MAXIMIZING RESOURCE RECOVERY FROM SOLID WASTE

The term "recycling" is used often these days, usually in the context which leads one to believe that recycling of products has been going on for a long time, wherever and whenever an economic incentive exists.

Today, we frequently hear words or expressions such as pollution, pollution abatement, "urban ore", "cash for trash", solid waste, material resource recovery, landfills, dumps, etc. Some undoubtedly will prove to be ephemeral; others will live as long as our society demands.

We cannot engage in rancid rationalization. When we discuss solid waste management, we should examine and evaluate the economic advantages of material and energy resource recovery. Market strategies of consumer-oriented companies have contributed to the amount of solid waste, perhaps excessively at times with the no deposit—no return throwaways, individual packaging, etc., but the consumer is usually delighted with these innovative packaging methods and the conveniences associated with them. He perhaps does not realize that it may add to the price which he pays for the particular item.

We generate an ever-increasing quantity of solid waste. Approximately one-half by weight is a renewable resource such as paper with a relatively high calorific content. If all the 113,375,000 metric tons of residential and commercial waste disposed of yearly were incinerated and the heat recovered,

* Paper presented at the Symposium "Energy Recovery from Solid Waste", March 13—14, 1975.

this would amount to less than 2 percent of our total prime energy needs or less than 6 percent of the heat energy required for heating and cooling our residential and commercial buildings. Incineration of solid waste alleviates the disposal problem. It has several advantages when compared with landfill disposal. These are: (1) volume reduction by approximately 90 percent; (2) sterile residue (ash) for which several uses exist; (3) recovery of heat which can be used to produce steam at lower cost than any of the fossil fuels available at today's prices; and (4) air pollution can be reduced to the level required by federal, state and local laws through the use of wet scrubbers or electrostatic precipitators, usually more economically than in individual plants which are replaced. In addition, front-end recovery of certain material resources such as aluminum, copper, steel, etc., may be realized if the secondary materials markets warrant. The reclaim value of some of the materials in our solid waste varies significantly. Situations have developed in which the cost of separation has been greater than the sales value.

The calorific energy resource continues to increase in value and is one of the solid waste "components" for which there is a profitable and growing market. The heat energy may be extracted from "solid waste fuel" in several different forms: (1) shredded to produce "fluff", (2) pelletized, (3) gas, and (4) liquid or incinerated to produce steam for process use, etc. This analysis will evaluate the market for the heat energy when extracted in a conventional incineration process to produce steam for use in cooling, heating, or certain process requirements.

There are several markets or uses for the recovered heat. As examples:

(1) Process needs in *manufacturing facilities.*

(2) *Industrial parks* in which process and/or factory comfort cooling or heating is required.

(3) *Metropolitan urban or commercial areas* where new as well as existing offices, stores, banks, hotels, etc., require year-round climate control.

(4) *College and university campuses* with existing central heating and cooling plants serving academic, dormitory, administration, student union, library and other areas on campus.

(5) *Medical centers* with diverse usage such as laboratory, research, surgery, patient and administrative areas.

(6) *Airport complexes* where central heating and cooling facilities provide environmental control for each building.

(7) *Shopping centers* where sales areas, malls and miscellaneous spaces are supplied with coolant and medium-temperature water for control of temperature and humidity.

(8) *Apartment complexes* with several high-rise facilities as part of an urban development program.

(9) *Power generation* where solid waste heat energy may serve as supplement to the prime energy for base load or peak shaving usage.

Each of these applications or markets requires a different amount of coolant and heat per unit of demand. In other words, each will have a different load factor. Reference to "load factor" throughout this paper refers to the ratio of yearly unit sales or usage to the yearly production.

Potential yearly production must allow for the scheduled and unscheduled outages of the incineration equipment. Expressed more succinctly, load factor is the steam sales and/or equivalent metric ton-hours per year divided by steam produced. In-plant usage, line losses and miscellaneous losses therefore are excluded.

The load factor range for each of these applications as derived from ASHRAE studies is shown on Table 1. Specifically, a manufacturing process which requires a fixed quantity of steam each operating hour will have the highest load factor of any of the markets analyzed. The demand is affected solely by the production process. It is not dependent upon the weather or outside conditions which affect transmission and ventilation air heating.

TABLE 1

Load factors

Applications (markets)	
(1) Manufacturing facility	
(process use only)	0.70—0.80
(2) Industrial park	
(heating only)	0.25—0.35
(heating and cooling)	0.50—0.60
(3) Metro urban area	
(heating and cooling)	0.60—0.70
(4) University campus	
(heating and cooling)	0.40—0.50
(5) Medical center	
(heating and cooling)	0.47—0.57
(6) Airport complex	
(heating and cooling)	0.55—0.65
(7) Shopping center	
(heating and cooling)	0.35—0.45
(8) Apartment complex	
(heating and cooling)	0.37—0.47

The second market of Table 1 has one condition — that when only building heating is required, the consumption will be minimal. If heating and cooling of the facilities in an industrial park are provided, this year-round need for steam improves the load factor. However, the consumption in spring and fall is quite low. During these periods, excess steam is condensed unless another use is available.

The remainder of the markets listed in Table 1 in which the cooling and heating needs are influenced primarily by the weather all have substantially the same seasonal demands and yearly load factor. In some instances the internal feature of the cooling load has a noticeable impact on the consumption.

The load factor has a significant impact on production cost, since it affects the revenue available from either steam, medium- or high-temperature water, or coolant. It is axiomatic that the higher the load factor the lower the production cost; therefore, applications such as manufacturing with a daily and year-round demand for heat energy will have the lowest production cost.

Initial investment for a solid waste incinerator facility with heat recovery and pollution control equipment will be affected by several different factors; specifically:

(1) Plant capacity.

(2) Type of pollution control equipment.

(3) Type of solid waste preparation and handling system.

(4) Type and quality of heat energy produced together with type of fluid used for transfer from plant to point of usage.

(5) Area of country (i.e., Northeast, Southeast, West, etc.).

Some of these data may be incorporated in curves such as shown in Fig. 1. From previous studies the data developed have been collected and interrelated for budget cost estimates for a typical incinerator design. These curves apply only to the Southeast area of the United States. Specifically, the heat recovery equipment consisting of water wall furnace, main heat exchanger, superheater and economizer section. A moving grate assembly, which provides "turnover" and mixing to obtain more complete combustion, would also be incorporated in the overall design and operation of the incinerator.

The building is of standard industrial type construction with solid waste storage pits sized for at least three full days of operation. Also included are auxiliary oil burners and forced and induced draft fan assemblies. The stack gas pollution control equipment is for both particulate and gaseous pollutants. The piping, wiring, controls, on-site labor, and site preparation are included in the budget curve. Also included are fees for financing, design, legal work, and cost of money during the constructing period. These items are shown under A in the figure.

When initial investment for the basic plant has been determined from Fig. 1 and distribution system(s) type and length have been established, these budget costs may be added to the basic plant cost and a total or new budget cost per metric ton determined. This new cost may be used to calculate fixed charges.

The distribution system(s) costs will vary depending on the type of fluid; namely, steam or hot water and chilled water for service to an industrial park, medical center, airport, urban development, etc. Assuming a representative length for the distribution (namely, comparatively short run for only steam to a manufacturing plant and an extensive "finger"type distribution system for the two commodities to serve an urban development project), the types of piping and insulation excavation, filling, and resurfacing as required, a budget cost for this portion of the project can be established and then added to the base costs obtained from Fig. 1 to obtain a complete financial analysis.

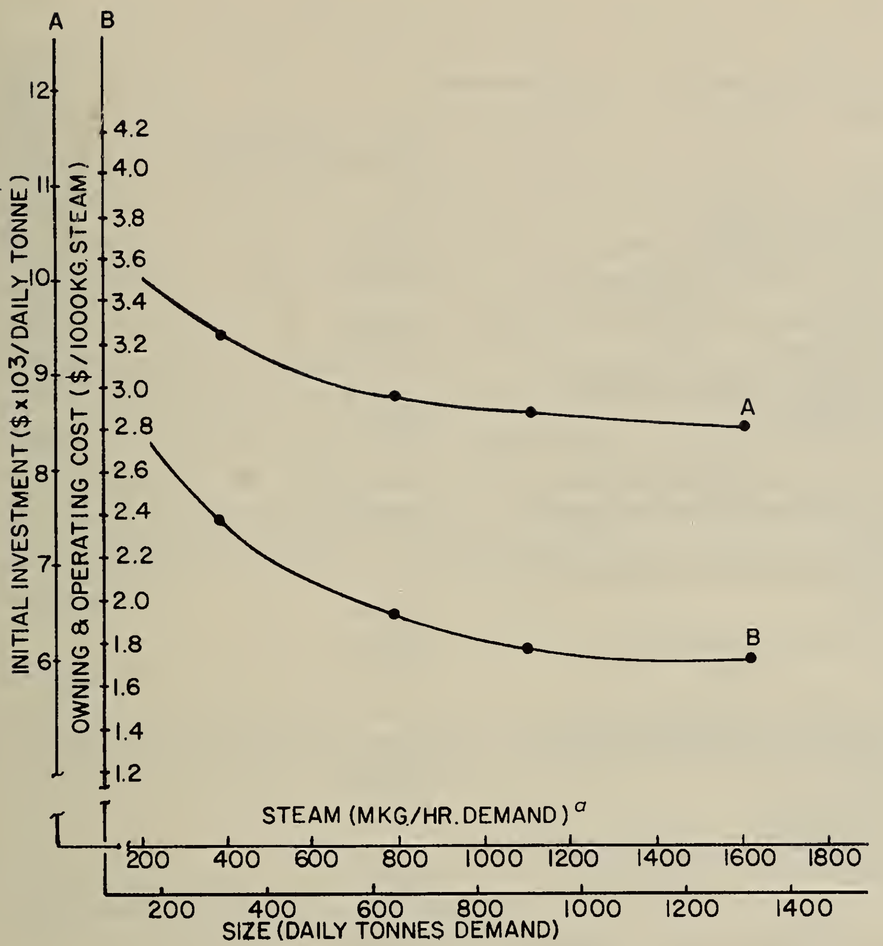

Fig. 1. Budget cost for incinerators applicable to southeast area U.S. and adjusted to 1975 level. (A) Initial investment includes incinerator unit with waste heat recovery, pollution control equipment, stack and breeching, building with solid waste storage, piping, wiring, controls, charging system, on site labor, fees, supplementary fuel facilities, financing cost during construction. (B) Owning and operating cost includes fixed charges based on 20 year depreciation, 7% interest, taxes, insurance, operating personnel, electricity, supplementary fuel, water, chemicals, routine maintenance, service contracts and with yearly load factor = 0.50.

[a]Based on 2500 kcal/kg solid waste 65% conversion efficiency.

The incremental costs for the distribution system and complementary changes in the incineration plant are shown in Table 2.

The cost additions are expressed as multipliers on the base cost of a conventional incinerator plant. As an example, to provide 150 psi (1.03×10^6 Pa) steam to a manufacturer as shown by line A-2, base cost will be increased by 6 percent. This presumes a close coupled arrangement with plant on the manufacturing site and the steam and condensate routed for minimum interference.

Should both coolant and steam be provided to several manufacturers in an industrial park as shown by line B-2, the base cost will increase 56 percent.

TABLE 2

Initial investment multiplier (for use with Fig. 1 curve A)

	Invest. multiplier
(A) Manufacturing (process use only)	
(a-1) Steam at 15 p.s.i. (1.05 kg/cm^2)	1.080
(a-2) Steam at 150 p.s.i. (10.55 kg/cm^2)	1.060
(a-3) Steam at 265 p.s.i. (18.6 kg/cm^2) and 38° C superheat	1.050
(a-4) Steam at 400 p.s.i. (28.1 kg/cm^2) and 66° C superheat	1.045
(B) Industrial park	
(b-1) Steam at 150 p.s.i. (10.55 kg/cm^2)	1.060
(b-2) Steam at 150 p.s.i. (10.55 kg/cm^2)	1.560
(C) Metro urban complex	
(c-1) Steam at 150 p.s.i. (10.55 kg/cm^2) coolant at 5° C	2.050
(c-2) Water at 143° C, coolant at 5° C	2.000
(D) University campus	
(d-1) Water at 143° C, coolant at 5° C	2.210
(d-2) Steam at 150 p.s.i. (10.55 kg/cm^2) coolant at 5° C	2.260
(E) Medical center	
(e-1) Steam at 150 p.s.i. (10.55 kg/cm^2) coolant at 5° C	2.170
(F) Airport complex	
(f-1) Water at 143° C, coolant at 5° C	2.130
(G) Shopping center	
(g-1) Water at 143° C, coolant at 5° C	2.120
(H) Apartment complex	
(h-1) Water at 143° C, coolant at 5° C	2.100

In this instance, a chilling plant is required and the facility will be located on the complex. Two distribution systems with laterals are required, hence approximately a 50-percent increase over the basic cost.

The metro urban complex, (market C), university campus (market D) and the remaining markets analyzed require heating either in the form of medium-temperature water or steam and coolant at about 5° C.

The increase in initial investment over that for the base plant is about 100 percent. This includes the chilling plant with auxiliaries such as heat rejection equipment, low head and primary pumping equipment, piping, service valves, etc., and building. The incinerator facility would be remote and the services may be in the street, therefore an additional premium for the distribution systems would be added.

The data gathered from various feasibility studies prepared during the past several years have served as a basis for the design and description of the solid waste facility referred to in the preceding paragraphs. Total initial investment, thus determined, can be used for budgeting purposes. Also, fixed charges may be readily calculated. Included, however in Fig. 1, curve B, are owning and operating cost data for the basic plant when operated at a load factor of 0.50. Bases for depreciation, value of money, etc., are indicated.

The owning and operating cost correction factors used for the different type distribution systems and plant modifications for the different applications are shown in Table 3. This multiplier, when used with curve B, will provide for budgetary purposes the cost of steam production when the plant load factor is 0.50. As an example, assume owning and operating costs for an incinerator plant serving a metro urban complex are required. This figure must include increased fixed charges for plant modification and for the distribution systems over and above those indicated by curve B. With load factor of 0.50 and with steam at 150 p.s.i. (1.03×10^6 Pa) for heating and coolant at 5°C for cooling and dehumidifying, the multiplier for "C-1" is 1.714 — in other words, 71.4 percent more than indicated by curve B. This presumes the load factor is 0.50.

TABLE 3

Owning and operating cost multiplier (for use with Fig. 1 curve B)

	Fixed charge multiplier
(A) Manufacturing (process use only)	
(a-1) Steam at 15 p.s.i. (1.05 kg/cm²)	1.055
(a-2) Steam at 150 p.s.i. (10.55 kg/cm²)	1.041
(a-3) Steam at 265 p.s.i. (18.6 kg/cm²) and 38°C superheat	1.034
(a-4) Steam at 400 p.s.i. (28.1 kg/cm²) and 66°C superheat	1.034
(B) Industrial park	
(b-1) Steam at 150 p.s.i. (10.55 kg/cm²)	1.041
(b-2) Steam at 150 p.s.i. (10.55 kg/cm²) coolant at 5°C	1.381
(C) Metro urban complex	
(c-1) Steam at 150 p.s.i. (10.55 kg/cm²) coolant at 5°C	1.714
(c-2) Water at 143°C, coolant at 5°C	1.680
(D) University campus	
(d-1) Water at 143°C, coolant at 5°C	1.823
(d-2) Steam at 150 p.s.i. (10.55 kg/cm²) coolant at 5°C	1.857
(E) Medical center	
(e-1) Steam at 150 p.s.i. (10.55 kg/cm²) coolant at 5°C	1.796
(F) Airport complex	
(f-1) Water at 143°C, coolant at 5°C	1.768
(G) Shopping center	
(g-1) Water at 143°C, coolant at 5°C	1.762
(H) Apartment complex	
(h-1) Water at 143°C, coolant at 5°C	1.748

Table 1 indicates the load factor range for different applications. Corrected production costs due to deviation from the base load factor of 0.50 to that applicable to the application under consideration may be obtained from Table 4. For a metro urban complex C a multiplier of 0.843 is used to correct from 0.50, the basic load factor used for curve B in Figure 1, to 0.65, the average for such applications. The net correction, therefore, is 1.714× 0.843 = 1.445. Subsequent calculation will amplify on this correction procedure. These multipliers take into account the relative impact of owning as well as all operating costs.

TABLE 4

Load factor multiplier (for use with Fig. 1)

Application (market)	Load factor multiplier
(A) Manufacturing (process use only)	0.816
(B) Industrial park	
(heating only)	1.445
(heating and cooling)	0.936
(C) Metro urban complex	0.843
(D) University complex	1.081
(E) Medical center	0.976
(F) Airport complex	0.883
(G) Shopping center	1.187
(H) Apartment complex	1.141

Generally speaking, the fixed charges for the incinerator facility with heat recovery, proper pollution control for both gas and liquid effluent, chilling plant, distribution system, etc., will be approximately 65 to 68 percent of the overall owning and operating costs. Of the remaining 32 to 35 percent, about 18 to 20 percent of owning and operating costs (that is, 55 percent of operating costs) is independent of plant output. This segment of costs includes operating personnel management, and general administrative expense. Other operating costs such as electricity, water, chemicals, supplementary fuel, and routine maintenance and service vary with steam production. This segment is approximately 45 percent of operating costs or about 15 percent of owning and operating expenses. As a result, the higher the load factor and yearly production, the lower the production costs. Expressed in another manner, if the system load factor were increased from the base factor of 0.50 to 0.60 (an increase of 20 percent), the total costs would increase only about 3 percent. In addition, if there were a 20-percent increase in gross income with only a 3-percent increase in owning and operating costs, the unit selling prices could be reduced if it were a "not-for-profit" operation or the profit picture would be enhanced if a profit-making corporation.

As an example of the foregoing, assume that budget costs are required for (1) initial investment; (2) fixed charges; (3) owning and operating costs; and (4) production costs for a 1,000 ton per day (907 metric ton) solid waste capacity plant with chilling plant sized for a heating to cooling demand ratio of 1.0 and serving an urban area with new and existing offices, stores, banks, hotels, etc.

Table 1 indicates that the load factor for metro urban areas will vary between 0.60 and 0.70. This information will be used later.

Figure 1, curve A, indicates that initial investment for a 1,000 ton per day (907 metric ton) basic plant is \$ 8,000 per ton (\$ 8,820 per metric ton) or \$ 8,000,000. Included in this figure are costs as listed in Fig. 1, item A.

Table 2 shows the multiplier for addition of distribution system and chilling plant. For application to market C, "metro urban complex" (using steam at 150 psi [1.03×10^6 Pa] for heating and 5°C coolant), the indicated correction factor is 2.050. The revised investment figure is \$ 8,000,000 × 2.05 = \$ 16,400,000.

Fig. 1, curve B, indicates the overall owning and operating costs for a base plant when operated at a load factor of 0.50. From curve B, the owning and operating costs or production costs are \$ 1.79 per 1,000 kilograms of steam.

Table 3 shows adjustment in owning and operating costs (production costs) because of the additional expense of distribution system and chilling plant. This correction multiplier for C (metro urban complex), with steam for heating and water for the coolant is 1.714; therefore, production cost is \$ 1.79 × 1.714 = \$ 3.07 per 1,000 kilograms of steam. This is the cost if the load factor were 0.50.

Table 4 shows the correction due to the metro urban complex load factor of 0.60—0.70 (use 0.65) instead of the 0.50 which is the basis for curve B in Figure 1. This correction factor is 0.843. Therefore, production costs are \$ 3.07 × 0.843 = \$ 2.59 per 1,000 kilograms of steam.

The result of the above exercise is:

(1) In-place cost for plant with distribution system is \$ 16,400,000.

(2) Production cost for services to the metro urban complex having a load factor of 0.65 is \$ 2.59 per 1,000 kilograms of steam.

Information such as this may be used during the preliminary stages of discussion and before the feasibility study is complete.

Should there be interest in return on investment at this preliminary stage, it is approximately 5 percent based on sales at \$ 3.86 per 1,000 kilograms of steam, initial investment of \$ 16,400,00 per metric ton capacity, and conversion efficiencies which provide 2,470 kilograms of steam per metric ton (103 kilograms of steam per hour per metric ton of waste). However, if the municipality pays a nominal amount for incineration in lieu of landfill (namely, \$ 2.72 per metric ton), the return on investment will be approximately 11 percent.

In time, economical techniques for recycling of certain components and markets should develop which will provide additional income. Supplementary income for paving base or building block can be obtained from the residue after separation.

In conclusion, there will be an ever-increasing amount of solid waste. Disposal will surely utilize the most economical techniques consistent with the air, water, and land pollution constraints. Conventional incineration and pyrolysis — processes in which the energy may be recovered and put to an economical and useful purpose — are disposal methods which appear to have merit.

Engineers are frequently called upon to evaluate the economics of the many different disposal methods for our ever-increasing amounts of solid waste. After a comprehensive study, they can recommend to the municipality the best solution to the disposal problem. Some sections of our country do not have sufficient amounts of certain low-cost convenience fossil fuels to serve the needs of all industries in their area. The heat energy in our solid waste may be a partial answer to this problem.

This study may be helpful in analyzing problems and provide preliminary information for budgeting purposes. The data could be used for preliminary discussion prior to a more comprehensive study.

Resource Recovery and Conservation, 1 (1976) 207—216

ENERGY AND RESOURCE RECOVERY FROM SOLID WASTES*

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(Received 19th March 1975)

INTRODUCTION

In 1969, long before the present awareness of energy shortages and depleted resources, the Occidental Research Corp. (formerly Garrett Research and Development Company, Inc.), a subsidiary of Occidental Petroleum Corporation, set out to develop a process that would recover oil and other resources from municipal refuse. A basic decision was made initially — the object of the research was not to produce the least cost waste disposal system, but rather to produce grades of recovered material which could find a ready and high value market. The results of this research and marketing are summarized here.

PROCESS DESCRIPTION

A simplified flow diagram of the Occidental Energy and Resource Recovery process is shown in Fig.1 and incorporates the following operations:

(1) Primary shredding of the raw refuse to smaller than 7.6 cm (3 in.).

(2) Magnetic separation of ferrous metals.

(3) Air classification to remove most of the inorganic material from the pyrolysis feed.

(4) Drying of the shredded refuse to about 3 percent moisture.

(5) Screening of the dry material to reduce the content of free inorganic material to below 4 percent by weight.

(6) Recovery of aluminum, and a clean glass product.

(7) Secondary shredding of the organic material to pieces smaller than 1.168 mm (14 mesh).

(8) Flash pyrolysis of the organics.

(9) Collection of the pyrolytic products under rigid pollution control conditions.

All of these operations, except primary shredding which was conducted under contract elsewhere, were studied in detail, both individually and in various combinations. They may be grouped and evaluated as two distinct

*Paper presented at the Symposium "Energy Recovery from Solid Waste", March 13—14, 1975.

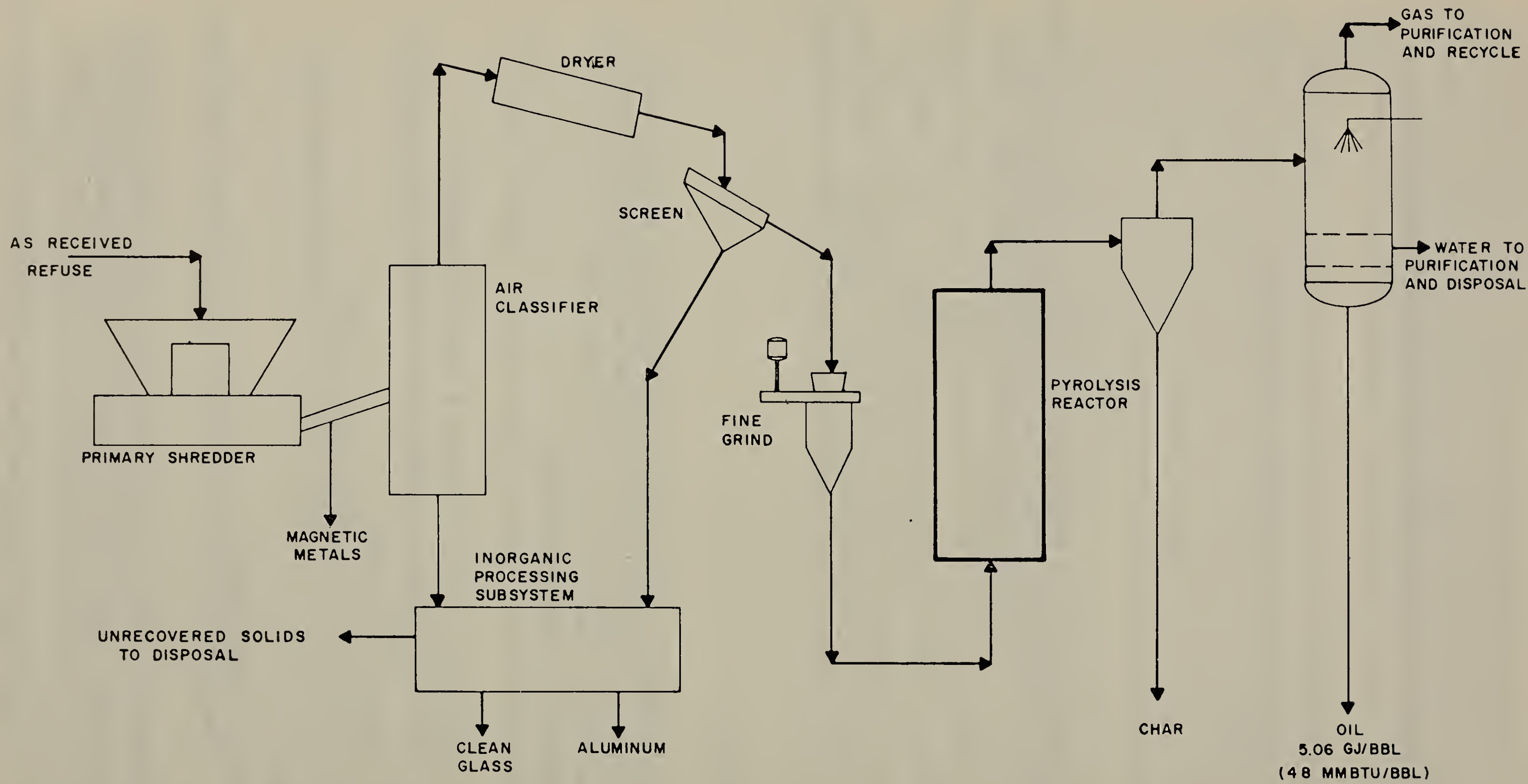

Fig.1. Recycling of solid wastes via pyrolysis.

subsystems — feed preparation, including recovery of metals and glass; and pyrolysis, including the recovery of salable fuels.

Feed preparation. The primary purpose of the feed preparation subsystem is to deliver dry, finely divided, essentially inorganic-free feed material to the pyrolysis reactor. An important secondary purpose is to allow the economic recovery of magnetic metals, aluminum and clean glass. During investigations of this subsystem, several combinations of the various unit operations were evaluated in order to develop the most efficient process with respect to product quality and operating costs.

One of the more important functions of the feed preparation subsystem is to minimize the content of the inorganic materials in the pyrolysis feed material. While the pyrolysis process itself is virtually unaffected by the inorganics, these materials degrade the quality of the residual char and increase maintenance costs for secondary shredding. During the early phases of the pilot plant program, it was thought that the free inorganic content of primary shredded wastes could be reduced to less than 4 percent by merely drying the refuse before air classification; however, it was determined that air classification must precede the drying step and air classifiers are now a standard item in the process chain.

Separating ferrous metals from refuse is relatively simple and is done magnetically. This is a well established process. However, it was found that recovery of glass and aluminum required development of entirely new techniques.

Glass recovery process. The glass recovery process developed uses froth flotation (a process well-known in minerals beneficiation). An innovation was a new selective chemical reagent to cause the previously classified and ground glass to attach itself to the air bubbles generated in a froth flotation cell, leaving non-glass impurities behind. The process is shown schematically in Fig.2. About 70 percent of the glass contained in the as-received refuse can be recovered as a 99.7 percent pure product which, we have found, can command a good price in the glass container manufacturing market.

Aluminum recovery ("RECYC-AL"). In mid-1972, an assessment of non-ferrous metal recovery technology was made as part of our resource recovery effort. At that time, heavy media separation, and screening or hand sorting seemed to be the only processes under active investigation for treating municipal refuse. Upon consideration of markets for scrap aluminum, it became obvious that secondary metal processors would pay a high price for recovered metal only if it meets rather rigid specifications. Occidental thus decided upon a dry separation process using linear induction motors (LIM) to recover selectively electrically conductive metals from the shredded, air classified refuse.

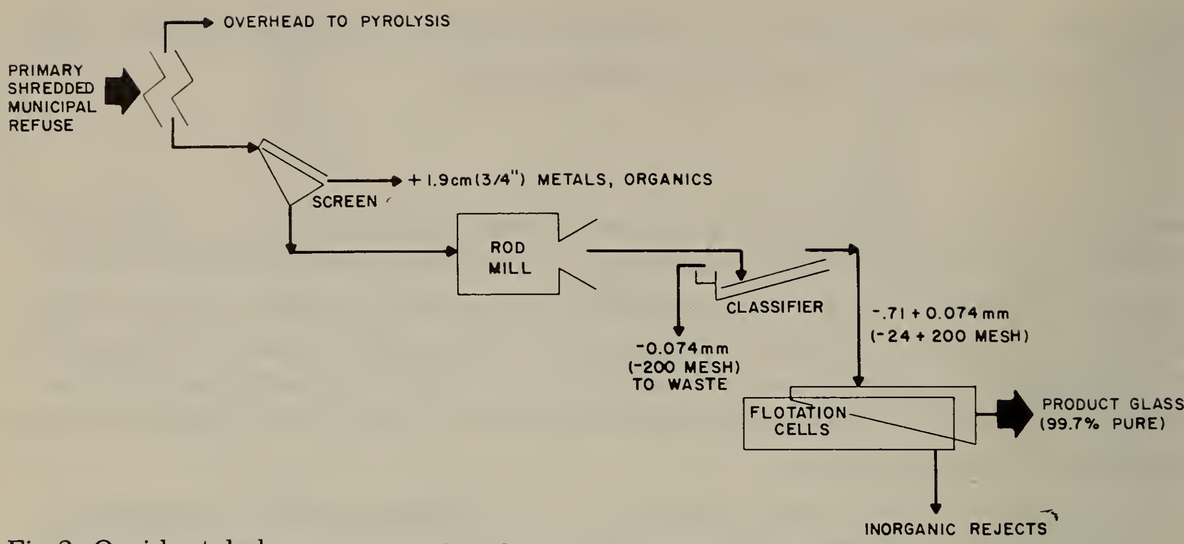

Fig.2. Occidental glass recovery process.

In the Occidental RECYC-AL process, shown schematically in Fig.3, one or more LIMs are positioned just beneath a non-conductive conveyor belt which is driven by a variable speed drive. Refuse that has been previously air classified and processed to remove magnetic metals is fed from a hopper onto the conveyor belt. The linear induction motors operate on an alternating current, variable-frequency power source. As the refuse containing aluminum passes over the LIM, eddy currents are induced in the pieces of aluminum, producing a magnetic field of opposite polarity to that field produced by the LIM. Because magnetic fields of the same polarity will repel each other, the resulting magnetic force causes the aluminum pieces to change direction rapidly toward the edge of the conveyor belt. A baffle positioned at the edge of the belt traps the aluminum, which then flows to

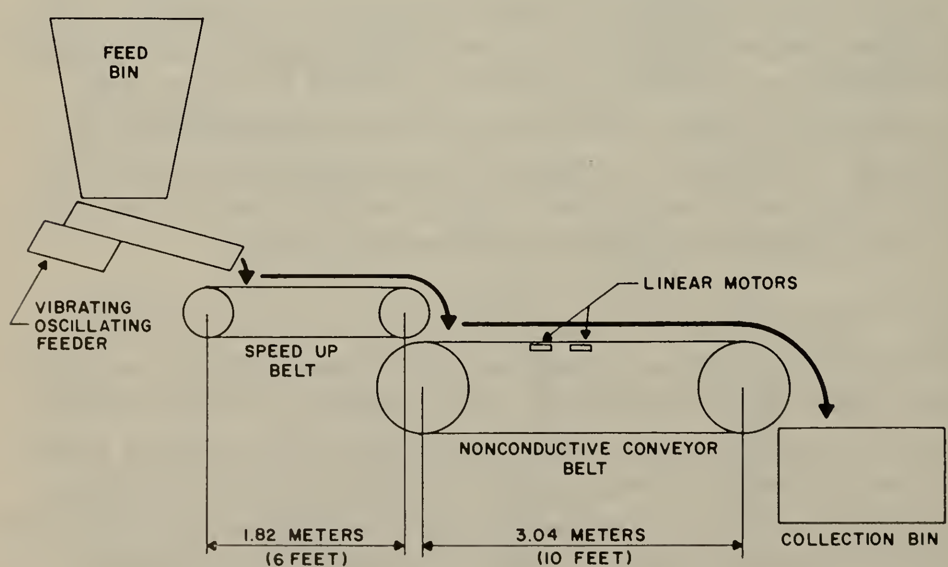

Fig.3. Occidental "RECYC-AL" aluminum separator process.

a product bin. The remaining refuse, which is essentially free of glass and metals, is then recycled back into the process. Nearly 60 percent of the aluminum present in the as-received refuse was recovered in experimental trials. The capacity of the pilot machine developed to date is 1.8 to 3.6 t (2 to 4 U.S. tons) per hour, of air-classified, screened rubbish usually containing from 7 to 20 percent aluminum. The particle size of the metal that can be recovered can be as small as 2.5 cm (1 in.) in the longest direction.

Secondary shredding. The heart of the Occidental feed preparation subsystem lies in the secondary shredding operation. A finely divided organic feed to the pyrolysis reactor is desirable if high oil yields at atmospheric pressure are to be achieved. Extensive vendor testing was conducted on five different units before a 40 hp, 454 kg (1000 pound per hour) hammer mill was installed for the pilot plant program. Prolonged testing over many months has shown that power requirements and maintenance costs using dry, essentially inorganic-free material from municipal refuse will result in acceptable operating costs.

Pyrolysis process. The Occidental pyrolysis process involves the rapid heating of finely shredded organic materials in the absence of air using a proprietary heat-exchange system. This technique was developed to maximize liquid fuel yields, thus generating the maximum income per ton of wastes. There are a number of solid waste pyrolysis processes under development today which maximize gas yields rather than liquids. However, pyrolysis of cellulosic feed stocks at gasification temperatures is usually endothermic by about 1400 to 1860 J/g (600 to 800 Btu/lb.), while the same reaction at 480°C (900°F) is slightly exothermic. Liquefaction is thus a more efficient conversion process and it also produces a more easily stored product which can be sold on the basis of its heating value.

During laboratory pyrolysis studies using a small continuous 2.26 kg (5 lb.) per hour reactor, oil yields of about 40 weight percent were obtained with dried municipal wastes from which about 90 percent of the inorganic material had been removed. These oil yields have now been confirmed on a larger scale using 3,628 kg (4 ton) per day pilot plant. Pyrolysis of cellulosic materials also produces a residual char, combustible gases, as well as by-product water. The distribution of these products has a significant effect upon the economics of the overall process. The gas produced under optimum liquefaction conditions has a moderate heating value of about 18.6×10^6 J/m^3 (500 Btu/ft^3) at the outlet of the reactor. This fuel is burned on-site for process heat and a portion of the char is also used for the same purpose.

DESCRIPTION OF RECOVERED PRODUCTS

Perhaps the most important aspect of any resource recovery system is the quality of the products to be returned to the economy. A great deal of negative comment has been generated during the past few years about the lack of suitable markets for recycled materials. In reality, the problem is not so much the markets but the quality of the recovered products. Magnetic metals heavily contaminated with organic material and non-ferrous metals will not find ready outlets, nor will any other contaminated commodity. A considerable amount of effort was thus spent on upgrading the quality of recovered materials.

Glass

The effort to produce high purity recycled products from municipal refuse is most graphically illustrated by the glass recovery process described earlier. More than 70 percent of the glass contained in packer truck waste can be recovered as a sand-sized, mixed-color product of greater than 99.7 percent purity. About two-thirds of the remaining impurities are carbonaceous, and these present little or no problem upon remelting for the manufacture of new containers.

Laboratory melt studies conducted by Owens-Illinois on sample cruets made from 100 percent recovered glass from the Occidental process have shown none of the normal imperfections often found in reclaimed glass. These imperfections are cords, stones, blisters or seeds, and none could be found at 10—power magnification.

Aluminum

Although the "separating" action of the RECYC-AL machine affects all conducting materials, there are considerable differences among various metals and configurations. It has been found that the RECYC-AL process minimizes the occurrence of such undesirable materials as stainless steel, lead and bismuth in the product stream. Because of the extreme qualitative variability in composition of the input of municipal waste, it is difficult to produce a standardized product. However, in experimental trials the RECYC-AL process has been found to reduce greatly the incidence of undesirable components in the product metal. At this stage in its development the process is not expected to produce aluminum consisting almost entirely of aluminum cans, but the product metal is expected to be composed of more than 90 percent by weight aluminum with small quantities of contaminant.

Markets for the recovered aluminum have been determined throughout the U.S. and many secondary metal processors are willing to make long term purchase commitments because of the consistent quality of the product that can be attained.

Pyrolytic oil

The Occidental system employs a pyrolysis process which converts the organic portion of municipal waste to usable synthetic fuel oil. The pyrolytic oil is, in fact, the single most important product obtained. As might be expected from its genesis, pyrolytic oil differs in many important respects from fuel oil derived from petroleum. The synthetic product is a highly complex, oxygenated, organic fluid rather than a hydrocarbon. The sulfur content is from 0.1 to 0.2 percent by weight, far lower than most petroleum based fuel oils. Because it is lower in both carbon and hydrogen than the latter, the average calorific value of the synthetic oil is about 24400 J/g (10,500 Btu/lb.) compared to 42,300 J/g (18,200 Btu/lb.) for a typical residual oil. However, since the densities of pyrolytic oil and typical No. 6 are 1.30 and 0.98 respectively, the fuel oils are generally sold by volume rather than by weight; a comparison of heating values is much more favorable to pyrolytic oil when expressed on a volumetric basis. Oil derived from the pyrolysis of municipal waste contains some 76 percent of the heat energy available from No. 6 oil.

It has been observed that pyrolytic oil is a good deal more viscous than a typical residual oil. This means, of course, that it must be stored, pumped and atomized at somewhat higher temperatures. Combustion tests with some 870 liters (230 gallons) of oil at the research facilities of a large manufacturer of power plant equipment have shown that the pyrolytic oil could be pumped without trouble at 71°C (160° F), and that satisfactory atomization was achieved with 0.3×10^6 Pa (50 psi) steam when 37,85 liters (10 gallons) per hour of oil was delivered to the burner tip at 0.2×10^6 Pa (25 psi) and 115°C (240°F). Atomization with cold compressed air at 0.7×10^6 Pa (100 psi) resulted in the formation of a much coarser droplet spray, and it is probable that preheating would be needed.

It was also found that pyrolytic oil can be compatibly mixed with most No.6 fuel oils. Laboratory tests have shown that equal quantities of each can be blended together to produce a relatively easy-to-handle two-phase mixture. This had not been anticipated. It was known that the heavier tar fuels obtained from the carbonization of coal cannot be mixed with petroleum oil fuels because of the precipitation of a gelatinous bituminous material, and it was feared that pyrolytic oil might also exhibit the same behavior. Further studies are planned on the storage, handling and combustion properties of blends of No.6 and pyrolytic oil. If further work confirms the compatability of the two fuels, blends can be tailored to take advantage of the superior properties of each. Thus, the high sulfur content of a residual petroleum-based oil can be reduced by the low sulfur pyrolytic oil, which in turn will have its viscosity lowered.

ECONOMICS OF THE OCCIDENTAL PROCESS

The Occidental pyrolysis process is designed as a flexible, pollution-free system which requires relatively low capital costs per ton of installed capacity. However, since there are a number of distinct feed preparation operations required, the process will be fairly labor-intensive until a semi-automated system can be developed. For this reason, the economics of scale currently have an appreciable effect upon operating costs. A summary of the estimated economics for a 2,000 ton/day plant is shown in Table 1. These operating costs include provision for a complete administrative staff of 13 people, from plant manager to clerks and secretaries. The plant itself will require nearly 60 operators for 24 hours per day, seven days per week — this labor has been estimated at $50,000 per year, per shift-job.

TABLE 1

Estimated economics of 1,816 t/day (2,000 U.S. ton/day) solid waste pyrolysis plant

Total plant capital (excludes land)	$ 32,800,000	
Working capital	800,000	
Annual op. cost (amortization, 20 yrs. at 6%)	11,600,000	
Annual net revenue from sales	13,600,000	
Annual profit	2,000,000	
Cost per ton (350 days per year)		16,57
Net revenue per ton (350 days per year)		19,44
Net profit per ton		2.87

In addition to these attractive economics, the Occidental process is also thermodynamically efficient. The net thermal output of the plant, expressed in electrical terms, is developed in Table 2.

TABLE 2

Overall energy balance of 1,816 t/day (2,000 U.S. ton/day) Occidental solid waste pyrolysis process

Total energy in one ton as-received refuse[a]	10.548 GJ (10 MM Btu)
Energy in 1.1 bbl of oil per ton refuse	5.569 GJ (5.28 MM Btu) or 1,547 kWh
At a power plant conversion efficiency of 34%	
Recovered electric power per ton refuse	530 kWh
Consumed electric power per ton refuse	140 kWh
Net recovered electric power per ton refuse	390 kWh

[a] Assumes 25% moisture

The pyrolysis process has been shown to be an attractive alternative for recycling tires, tree bark, rice hulls, and other waste products in experimental trials. Thus, the prospects for widespread utilization appear to be quite promising.

SOLID FUEL AS A PRODUCT

This paper has described the Occidental Resource Recovery System that produces, in addition to high grades of minerals, energy in the form of a pyrolytic oil. To prove the technical viability of the flash pyrolysis process on a commercial scale, a 181.5 t/day (200 U.S. ton/day) demonstration is presently being built in San Diego County, California,with funding by the Environmental Protection Agency. This technology will not be offered commercially until this demonstration is successful. The "front end" of this technology, however, is available with energy recovered as a dry fibrous solid fuel.

Bridgeport, Connecticut

After many months of extremely complex negotiations, a contract has recently been executed between the Connecticut Resources Recovery Authority and Occidental. Under the terms of this contract, Occidental will design, build and operate a 1,360 t (1,500 U.S. ton) per day facility in Bridgeport to serve a large part of Southwestern Connecticut. Virtually all of the municipal waste from the specified area will be disposed of by the Occidental plant and its associated transfer stations under a 22½ year contract. In addition to the innovative technology that will be used, the contract is a novel and remarkable example of successful cooperation between the public and private sectors.

Dry, fibrous fuel. The Occidental Resource Recovery System that will be installed in Bridgeport is schematically identical with the process described in the paper up to the stage of secondary shredding. In the Bridgeport process

TABLE 3

Estimated economics of 1,816 t/day (2,000 U.S. ton/day) resource recovery plant (solid fuel)

Total plant capital (excluding land)	$26,000,000
Working capital	650,000
Annual operating cost (amortization, 20 yrs at 6%)	9,500,000
Annual net revenue from sales [fuel at $1.00/1.054 GJ ($1.00/MM Btu)]	9,750,000
Annual profit	250,000
Cost/ton (350 days/yr.)	13.57
Net revenue/ton (350 days/yr.)	13.93
Net revenue/ton	0.36

line, the secondary shredder reduces the material only to a nominal 1.2 cm (½ in.) size, and the material will be then sent to a local utility for burning in conjunction with heavy oil. This fuel can be utilized only in boilers equipped with ash handling and "back end" cleaning equipment, or perhaps in cement kilns.

The economics of a full line resource recovery plant that will produce such a solid fuel are given in Table 3.

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FEASIBILITY STUDY FOR BURNING REFUSE-DERIVED FUEL IN THE DISTRICT OF COLUMBIA BY POTOMAC ELECTRIC POWER COMPANY*

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ABSTRACT

This paper describes a study conducted to determine the economic feasibility of a project for producing and burning refuse-derived fuel RDF in the District of Columbia. Alternate modes of processing,transporting, handling and burning RDF were considered. The study concluded that it is economically feasible to implement the project and identifies the most cost-effective approach for utilization of existing capital facilities. The study can possibly serve as a model for implementation of this form of energy recovery elsewhere.

INTRODUCTION

In May of 1974, a task force committee, consisting of representatives of the District of Columbia's Department of Environmental Services (DES), the Potomac Electric Power Company (PEPCO) and the National Center for Resource Recovery, Inc. (NCRR) was established to investigate the feasibility of a refuse energy recovery project in the District of Columbia. Specifically, the study was to consider the economic and design alternatives involved in the preparation of RDF at the DES Solid Waste Reduction Center Number 1 (SWRC-1), transportation to the adjoining PEPCO Benning Generating Station and firing of RDF in one of the boilers.

The District of Columbia generates in excess of 635,000 tons of solid waste annually. This refuse is collected by three classes of collectors; the District's Department of Environmental Services, the Federal Government, and by private commercial collectors. The collected refuse is disposed of by one of three methods: direct disposal at landfills operated by DES; delivery to one of three DES transfer stations, and after reloading, disposal at the landfill sites; and incineration of solid wastes followed by disposal of residues by landfill. The District presently operates three landfill sites, three transfer stations and one incinerator.

The Potomac Electric Power Company is an investor-owned utility serving 449,000 customers in a service area of 1.7×10^9 m^2 including Washington

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** Faculty Participation Research Fellow, National Science Foundation, Summer, 1974, at the National Center for Resource Recovery, Inc.

D.C., a portion of suburban Montgomery and Prince Georges Counties in Maryland and a small commercial area in Arlington County, Virginia. PEPCO's current generating capacity is from fossil-fueled facilities; however, two 1100-MW nuclear plants are scheduled to be added to the system.

The Benning Generating Station is located on a 186,000 m^2 site on the east bank of the Anocostia River in the District of Columbia and has seven generating units with a total capability of 751MW. Solid Waste Reduction Center Number 1 is located adjacent to the Benning Station and consists of six refractory-type refuse burning furnaces with a total capacity of 1500 tons/day. Incorporated in the design of SWRC-1 is a shredding facility and magnetic separator to shred oversize bulky waste prior to burning in the incinerator furnaces.

In March, 1974, NCRR entered into an agreement with DES to conduct a resource recovery test and demonstration program at SWRC-1. The resource recovery system utilizes the large (1000 hp = 746 KW) shredder, a suitable air classifier, and other equipment. For the NCRR program, the shredder is operated on household and commercial refuse. Considering the close proximity of the Benning Station and SWRC-1, it should surprise no one that, in a short period of time, a task force to study energy recovery was underway.

PROJECT CONSIDERATIONS

The project, as envisioned by the task force at its inception, was to consist of two, or possibly three phases. Each phase would be concerned with the evaluation of alternative modes of processing, transporting, handling and burning refuse-derived fuel. The primary purpose of the project, if implemented, was to develop firsthand information and experience in the following areas:

(1) processing of solid waste and production of RDF at SWRC-1 by DES,

(2) transportation of RDF by DES to Benning Station on a mutually agreeable schedule, and

(3) feeding and firing of RDF as supplemental fuel in a Benning Station boiler by PEPCO (Boiler No. 26 was selected on the basis of size and its capability for both oil and coal firing).

The benefits accruing to PEPCO and DES would include information and experience useful in determining the relative economics and benefits of the process, the evaluation of potential technical problems, and the development of new working relationships between the parties. All of the above would contribute to the determination of this form of resource recovery to DES as a significant means of disposal of solid waste and to PEPCO as a significant supply of an economical supplemental fuel.

Originally, the studies were to concentrate on achieving the project objectives at minimum cost and modification of existing facilities. For example, early in the study some of the possible RDF firing techniques which were considered included injection of RDF into the bunker, or the pulverizer, or the existing distribution piping. Subsequent investigations and conversations with equipment suppliers indicated that injection into a separate distribution system is preferred. Many technical ideas were pursued; most were abandoned early in their life. The final result was a detailed consideration of a two-phase program with several technical alternatives as described below.

Under both phases, RDF would be produced at SWRC-1 by primary and secondary shredding to a nominal particle size of less than 4 cm. Under Phase I, the RDF would be transported by DES to a receiving facility at Benning Station. DES would be responsible for the unloading of the vehicles and the transfer of RDF to the PEPCO receiving bin. From the bin, PEPCO would be responsible for pneumatically transporting the RDF to two corners of Boiler No. 26. If two corner burning was found to be unacceptable, the system would be modified to permit burning at four corners. Phase I includes testing, as described later.

Phase II differs from Phase I only in that truck transport of RDF is replaced by pneumatic conveying of the RDF directly from SWRC-1 to the PEPCO bin. The testing and evaluation for each phase are outlined below:

Phase I

(1) For PEPCO:
- a. Evaluate the RDF conveying and injection system as provided by the equipment supplier to include erosion effects.
- b. Perform fuel analyses of RDF as received.
- c. Evaluate effect of RDF burning on boiler performance-efficiency, slagging, corrosion, particulates, etc.
- d. Determine impact of RDF burning on air pollution control equipment and emissions.
- e. Evaluate the effect of RDF burning on the bottom ash handling system.
- f. Determine operating and maintenance costs.

(2) For DES:
- a. Modify existing equipment and install materials handling and separation equipment at the SWRC-1 as necessary.
- b. Determine operating and maintenance costs.

Phase II

(1) For PEPCO:
- a. Continue Phase I program to identify and resolve problems associated with RDF burning.

(2) For DES:
- a. Install and evaluate pneumatic transport line to PEPCO receiving bin.
- b. Develop design parameters and estimate capital and operating costs for a continuous full-scale system.

SYSTEM ALTERNATIVES

For each phase, the task force considered various alternatives for delivering RDF to Benning Boiler No. 26. In Phase I, four system alternatives were studied and are described below (see Figs. 1—4).

Option A — This system involves the trucking of RDF to a location south of SWRC-1 on DES property. The fuel would be loaded into a feed hopper and conveyed to a bin on PEPCO property in the vicinity of Boiler No. 28 cooling tower. From the discharge valve of the bin, RDF would be pneumatically conveyed to Boiler No. 26.

Option B — This option replaces the long conveyor between the feed hopper and bin of Option A with truck delivery to the bin located on PEPCO property as described above. The remainder of the system is unchanged.

Option C — This system involves the trucking of RDF to the east side of Boiler No. 26 where the feed hopper and bin would be located. This option reduces the length of the pneumatic conveyor of options A and B but requires truck unloading operations in this cramped and congested area.

Option D — For this option, RDF is trucked to the west side of Boiler No. 26. The PEPCO fence must be moved to accomodate a truck and the feed hopper. The bin, also located on the west side of Boiler No. 26, would be adjacent to the feed hopper but on the PEPCO side of the fence.

The equipment requirements common to all options, specific to each alternative, and the advantages and disadvantages of each system were identified and evaluated. Option D was selected as the Phase I system for detailed analysis and further study. The primary reason for the selection of this option is that it is the one of minimum interference with normal PEPCO operations — it does not require an additional gate or guard and also does not require that DES trucks enter PEPCO property. In addition, this option requires the shortest lengths of pipe from the bin to the boiler and, hence, lowest installed cost as compared to the other options.

For Phase II operations, the ideal location for the storage bin is the yard area at the east side of the unit to provide the shortest pipe route from SWRC-1 to the bin. It is not anticipated that the bin would be moved to this location after Phase I because the cost of moving, providing new foundations, and rerouting the feed pipes to the boiler would exceed the cost of a few hundred feet of additional pipe. However, if a decision should be made to bypass Phase I and start with Phase II, consideration would be given to locating the bin as mentioned above.

Costs for the installation and operation of equipment for the project were estimated for DES and PEPCO in three categories: (a) general project costs, (b) Phase I costs, and (c) Phase II costs.

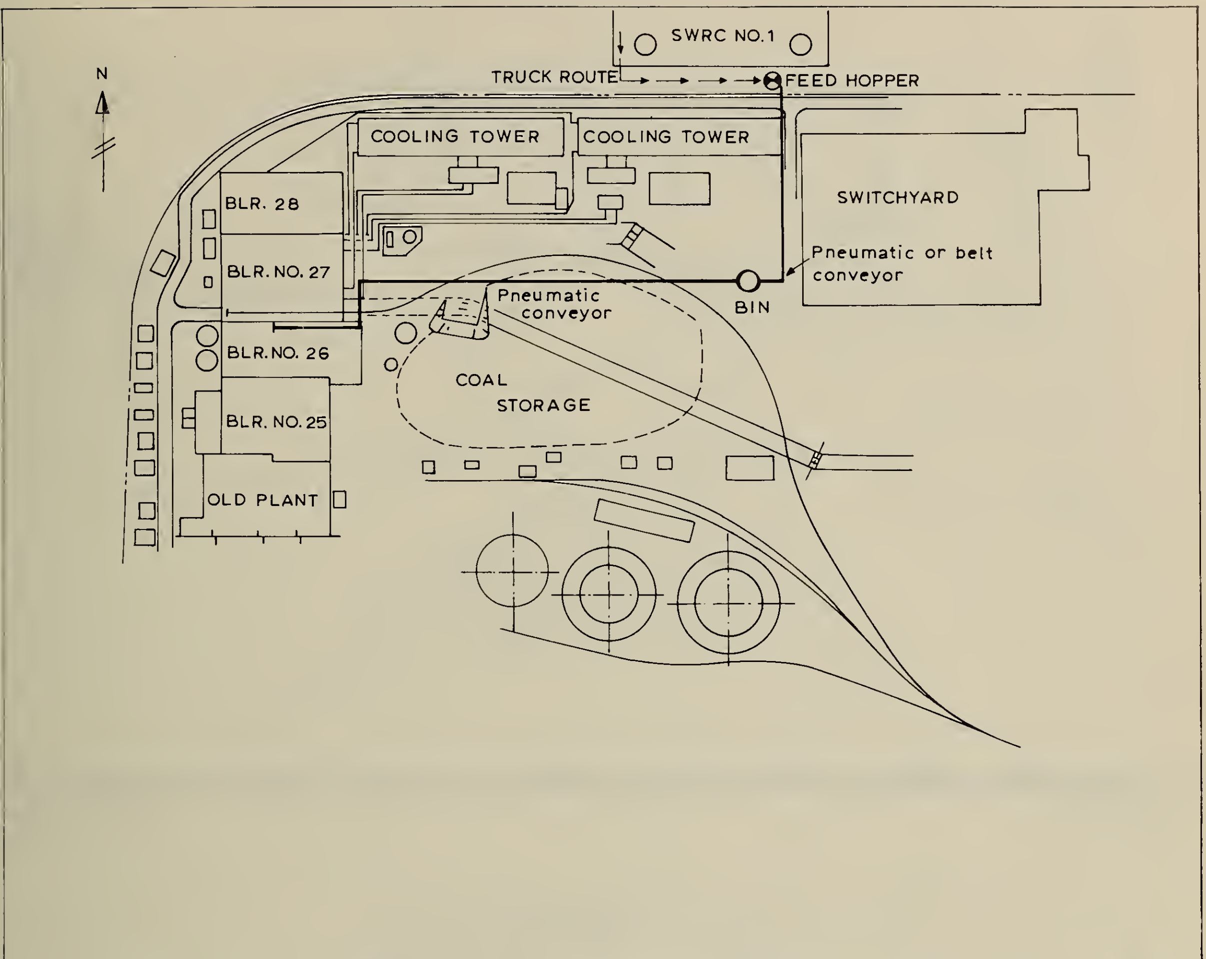

Fig. 1. Site plan of PEPCO Benning Generating Station indicating operational features of option A.

RECOMMENDATIONS AND CONCLUSIONS

The task force committee concluded that it is economically feasible to implement a pilot project for the production of RDF at SWRC-1 and its utilization in Benning Boiler No. 26. The most cost-effective approach to this project is to bypass the Phase I operations and to adopt the Phase II program. The costs and benefits utilized to arrive at the above conclusion are based on a facility processing 20 tons per hour of refuse and producing 14 tons per hour of RDF for 12 hours per day and 260 days per year.

The task force recommendations are:

(1) PEPCO modify boiler No. 26 to burn RDF using a system recommended by Combustion Engineering, Inc.

(2) DES modify its refuse processing facility to produce RDF on a continuous basis and of quality acceptable to PEPCO.

(3) DES construct a pneumatic transport system capable of delivering up to 20 tons per hour of RDF to PEPCO. The pneumatic piping extending within PEPCO's property should be donated or leased at a nominal fee to PEPCO and maintained by PEPCO.

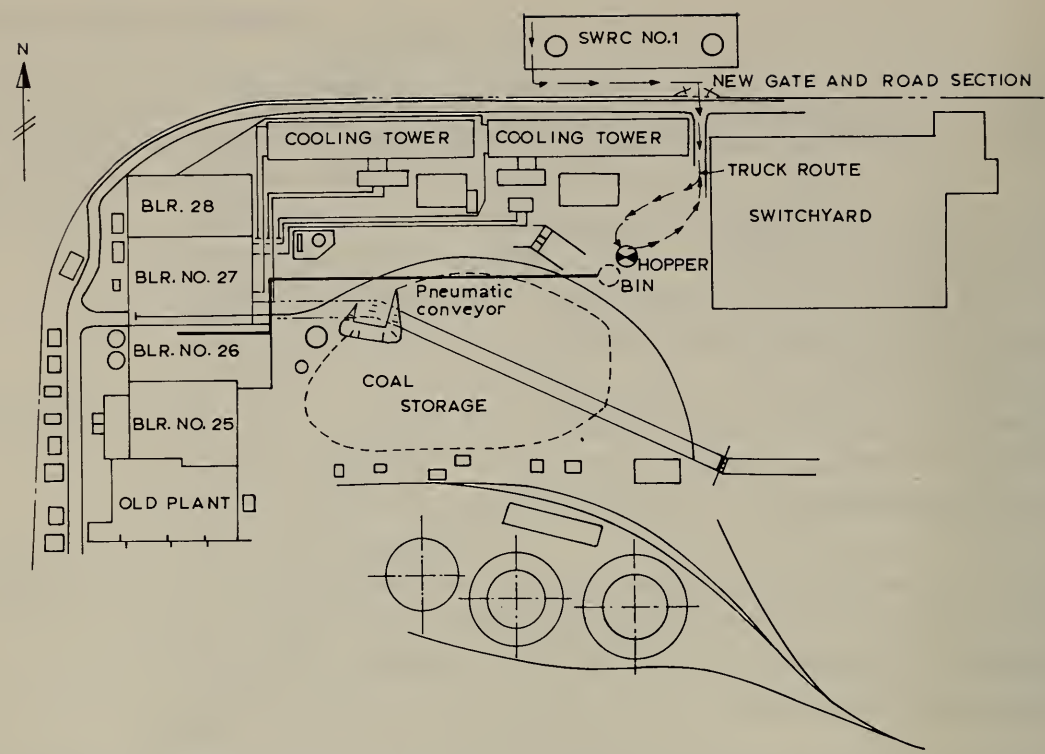

Fig. 2. Site plan of PEPCO Benning Generating Station indicating operational features of option B.

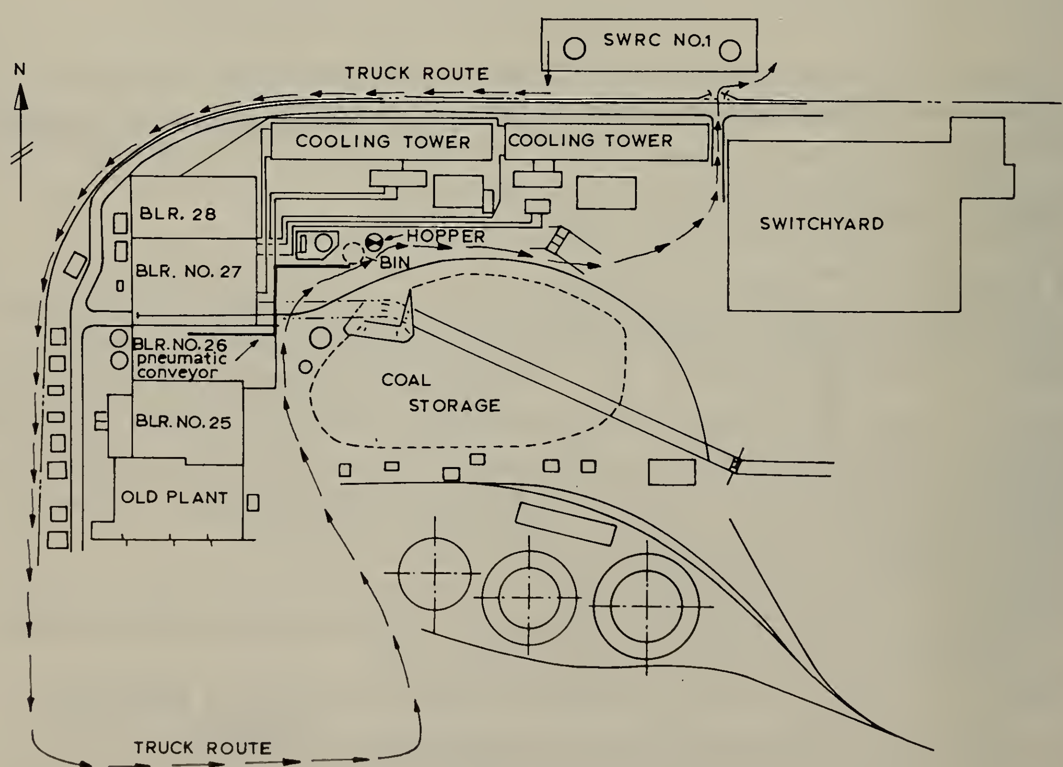

Fig. 3. Site plan of PEPCO Benning Generating Station indicating operational features of option C.

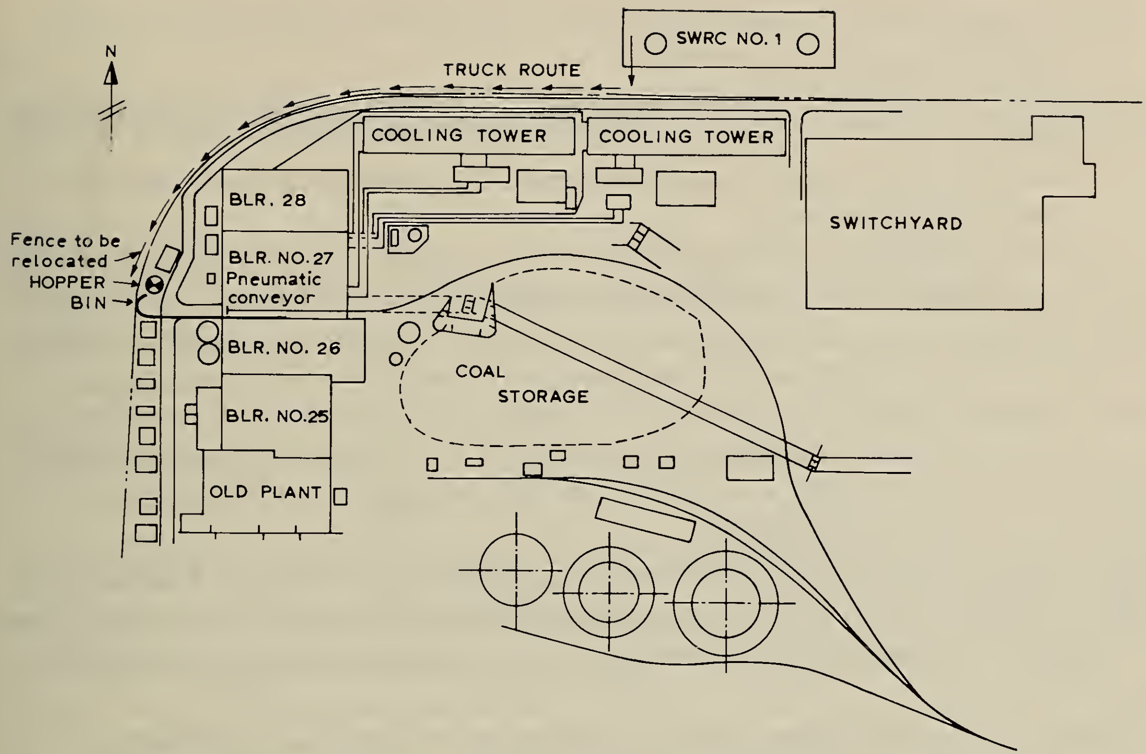

Fig. 4. Site plan of PEPCO Benning Generating Station indicating operational features of option D.

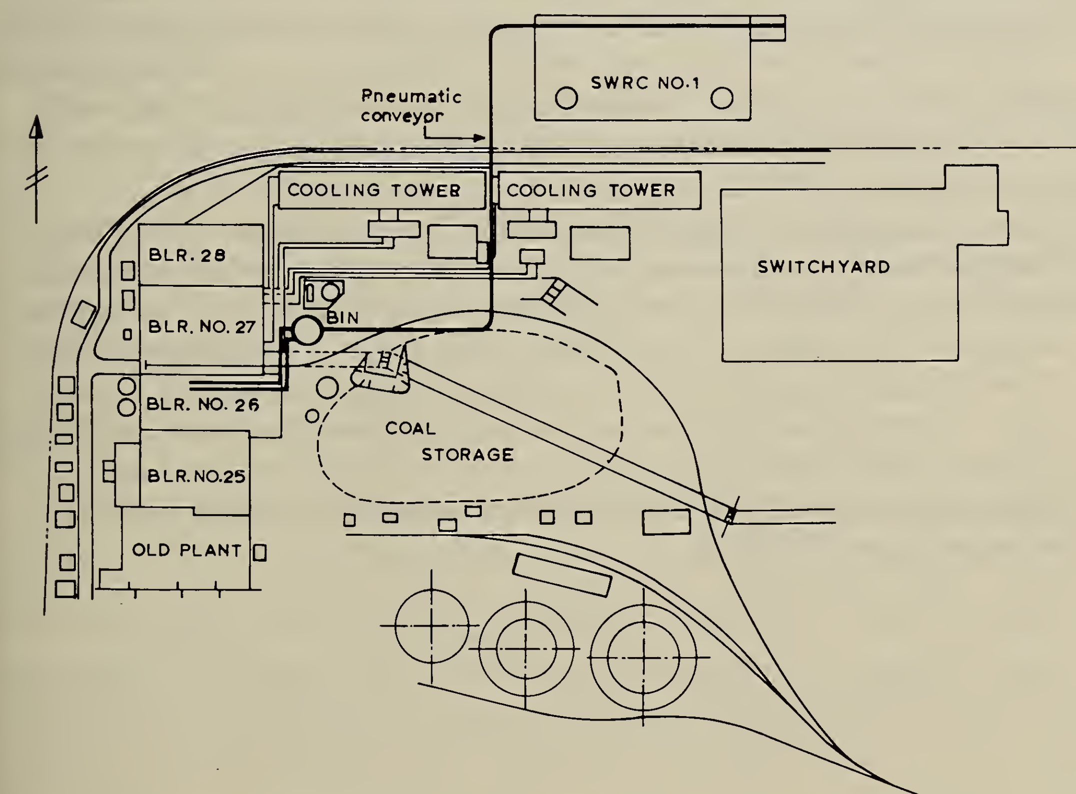

Fig. 5. Site plan of PEPCO Benning Generating Station indicating operational features of phase II.

(4) An agreement between PEPCO and DES for a pilot project of five operating years be executed.
(5) RDF be delivered at no charge to PEPCO during the first operating year.
(6) Benefits to be shared equally during the remaining four years of the initial agreement.
(7) The agreement be renegotiated at the end of the fifth operating year.

To avoid entagling this project in the larger and more complicated issue of fuel pricing, it was recommended that the net benefits be equalized. The net benefit for each party would be based on benefits for four years less capital costs and operating costs for five years. A benefit accrues to DES by not having to incinerate or transport to landfill the weight of material sent to PEPCO as fuel and PEPCO benefits by the savings in fuel costs from substitution of coal with RDF.

The average net benefit is obtained by summing the DES and PEPCO net benefits and dividing by two. The party with the highest net benefit then pays the difference between its net benefit and the average benefit to the other party.

The task force committee concludes that the project is an extremely advantageous undertaking from both the DES and PEPCO standpoints and offers a partial solution to the solid waste disposal problem within the District of Columbia.

During the planning process, the U.S. Environmental Protection Agency expressed interest in the project as an opportunity to investigate the co-firing of RDF with oil at low investment and within a relatively short time schedule. Encouraged by EPA, in April, 1975, DES submitted a grant application for partial federal funding of a greatly expanded project, with the remainder of funding from DES and PEPCO.

The project submitted for partial federal funding is a different one. The mutual benefit sharing aspects are not included; there is no payment for the fuel during the grant period. The fuel acceptance provisions do not interfere with the experimental nature of the project. First firing is planned approximately 16 months after grant award. Co-firing oil with secondary shredding of RDF will be investigated first, before co-firing with coal without secondary shredding. Plans include extensive monitoring of air emissions, including analyses of heavy metals and various organic compounds. Project funding and implementation are pending.

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UNION ELECTRIC COMPANY'S SOLID WASTE UTILIZATION SYSTEM*

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(Received 19th March 1975)

INTRODUCTION

Full scale testing to determine the feasibility of burning suitably prepared solid waste in an existing pulverized coal fired utility boiler has been underway by the U.S. Environmental Protection Agency, the City of St. Louis, and Union Electric Company since April 1972. Approximately 45,400 metric tons of St. Louis residential solid waste has been processed, providing a burnable supplementary boiler fuel of approximately 36,000 metric tons.

On February 28, 1974 the Union Electric Company announced that it would build, own, and operate a 7,300 metric tons per day solid waste utilization system (SWUS) capable of utilizing essentially all of the solid waste generated in the 1.2×10^{10} m^2 St. Louis metropolitan region with a population of about 2.5 million. The SWUS is scheduled for full operation on June 1, 1977.

The SWUS, estimated to cost $70 million, will be built with private funds. Revenue to support the investment and to cover operating costs will be generated by dumping fees, sale of recovered metals, and sale of the burnable fraction of the solid waste. The Union Colliery Company, a wholly owned subsidiary of Union Electric, will build, own, and operate the system and no monies to finance the system will come from the parent Company's electricity customers.

GENERAL DESCRIPTION

The St. Louis region covers 1.2×10^{10} m^2 and includes two states and seven counties in addition to the City of St. Louis. The region includes more than 150 governmental units and 150 public and private waste haulers. Current solid waste practices include landfill, incineration, and roadside and promiscuous dumps. Current solid waste generation including residential, commercial, and industrial waste is estimated to be approximately 7,300 metric tons (mt) per day. The projection for 1980 is 9,000 mt per day.

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*Paper presented at the Symposium "Energy Recovery from Solid Waste", March 13—14, 1975.

Union Electric Company is an investor-owned electric utility franchised to generate and distribute electricity in the eastern portion of Missouri and small areas in Illinois and Iowa. More than 90 percent of the Company's electricity is generated at pulverized coal-fueled steam-electric generating plants. The two power plants of particular interest to SWUS are the 2,400 MW Labadie Plant 60 km west of St. Louis and the 900 MW Meramec Plant about 32 km south of St. Louis. Coal consumption at Labadie is about 900 mt per hour and at Meramec about 360 mt per hour.

The St. Louis region is provided with railroads which radiate from the center of St. Louis like spokes in a wheel. Interstate highways and four-lane arterial roads also radiate from the core city and also encircle the metropolitan area. This railroad and road network, along with the remote location of the coal-fired power plants, provides for the efficient truck collection and rail transport of solid wastes to the isolated power plants.

Figure 1 is a diagramatic representation of the Solid Waste Utilization System. The previous arrangement for burning the refuse-derived fuel with coal (now operating under an EPA demonstration grant to the City of St. Louis) has been described [1].

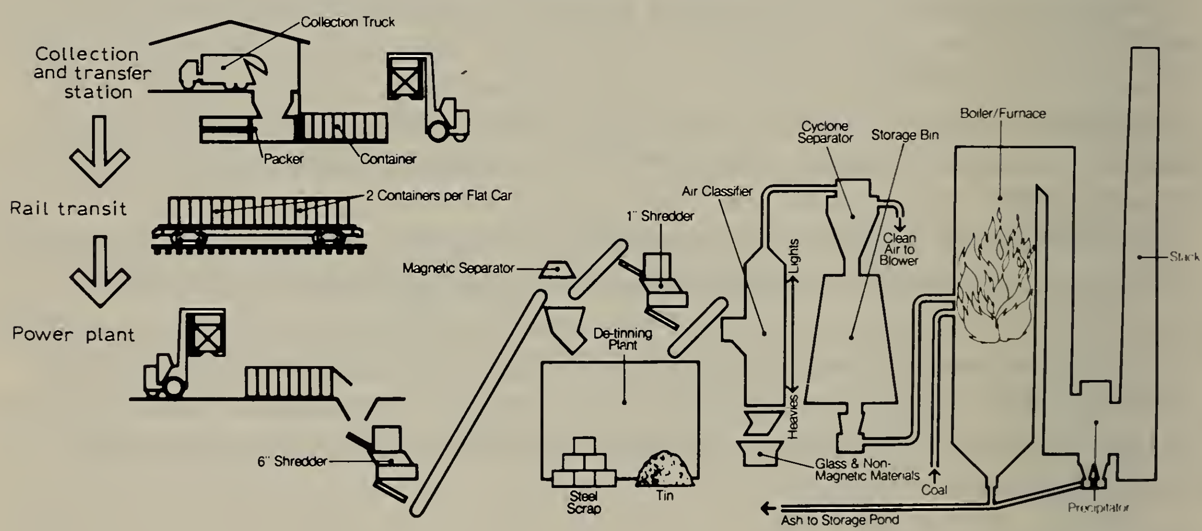

Fig.1. Flow chart of Union Electric Company's planned solid waste utilization system. Union Colliery Co., a wholly owned subsidiary, will build, own, and operate the S.W.U.S.

COLLECTION AND TRANSPORT

A totally owned subsidiary, the Union Colliery Company, will operate the SWUS but will not collect the solid waste where it is generated. Public and private trash haulers will be offered disposal service at five truck-to-rail transfer stations. These transfer stations will be located on arterial highways and/or interstate highways to preclude heavy truck traffic in or near residential areas.

A typical truck-to-rail transfer station will have a capacity of from about 1,300 to 1,800 mt per day. The smaller station can be expanded to the larger capacity. Residential, commercial, selected industrial, and selected demolition solid wastes will be accepted at transfer stations. Tires, appliances, demolition lumber, yard wastes, and size-reduced trees and trimmings will be accepted. Those wastes determined to be physically detrimental to the SWUS or classified to be hazardous to be handled in the SWUS by governmental agencies will be excluded. Only licensed trash haulers will be allowed to dump.

Trucks will be weighed before entering the totally enclosed transfer station building. A plan of a typical transfer station in shown in Fig.2. The trucks will enter the building and be directed to dump in conveyor dumping pits or on the floor, depending upon truck flow. All sizes of commercially available trash trucks will be able to use the facility including large (75 yard^3 = 57m^3) transfer trailer trucks.

Front-end loaders will lead the solid waste from the tipping floor to the stationary compactor conveyor. The front end loaders will also be able to tow a stalled trash truck if it breaks down in the building or on building

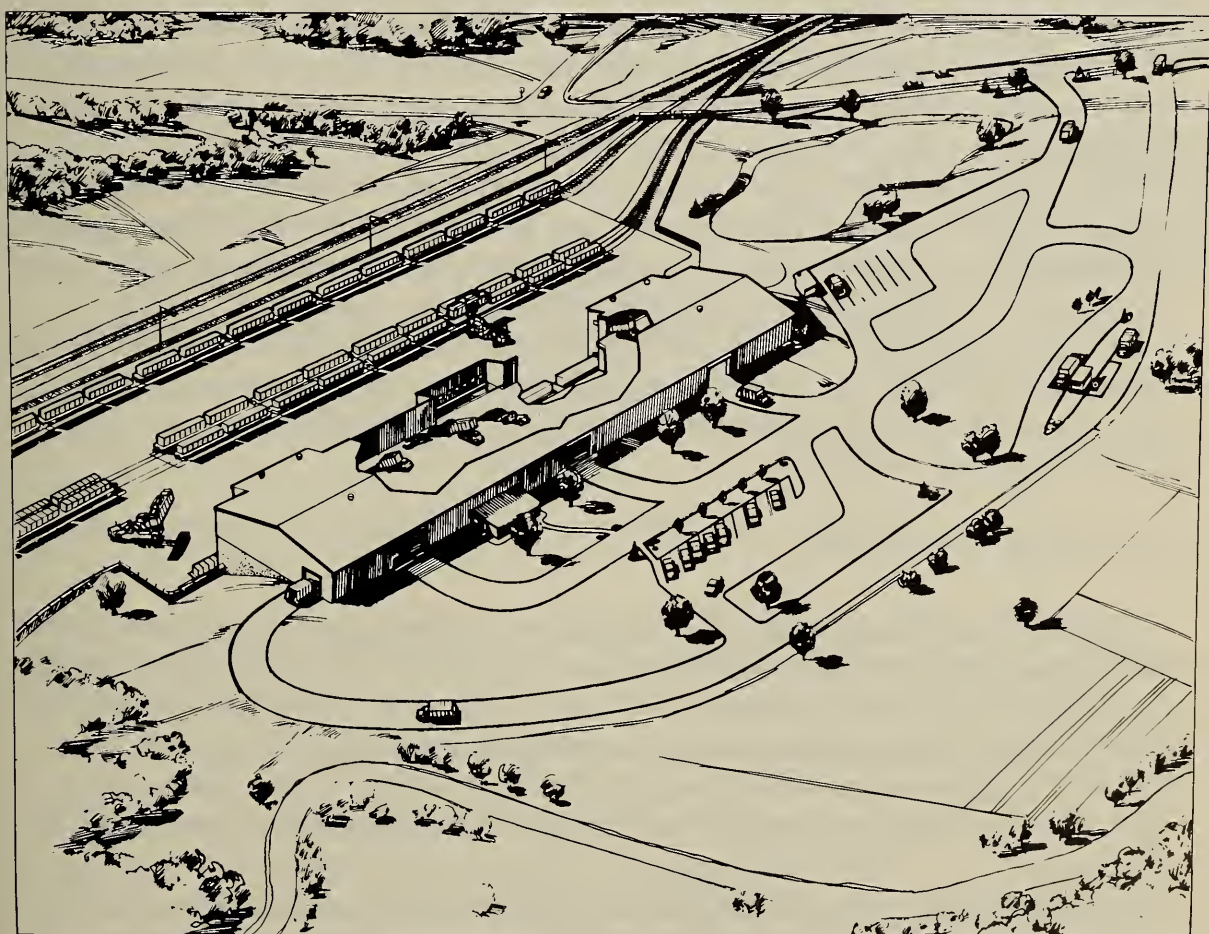

Fig.2. Typical transfer station plan. Site area approx. 90×10^3 m^2.

access roads. Present plans are to accept waste 16 hours per day, six days per week. Hours of operation will be scheduled to meet the demands of the haulers.

The solid waste will be loaded into 76 m^3 (100 $yard^3$) containers by conventional stationary packers having a nominal capacity of about 8 m^3. No solid waste storage will be provided for in the stationary compactor conveying pit and there will be only peak dumping storage on the tipping floor. Sufficient packer capacity is being provided to handle normal delivery, with only 2 to 3 h of peak delivery capacity being provided on the tipping floor.

The solid waste shipping containers are designed for a nominal capacity of about 69 m^3. The design is similar to conventional end-loading solid waste transfer trailer bodies. Two containers will be loaded on a conventional container on flat car. With a tare weight of about 9,000 kg (20,000 lb.) the container will carry a net solid waste payload of from 32 to 36 mt (35 to 40 tons).

The containers will be built to ISO and AAR standards for ship-board containers and can be carried on conventional ship container truck trailers. The 12m (40 ft.) long containers will be equipped with a telescoping cylinder-operated ejection blade and a guillotine loading door.

The container will be set on a movable steel framework which will lock the container to the stationary packer. The loading door will be operated by hydraulic cylinders. Load cells in the container positioning frame will cut-off the packer when the container is full.

The containers will be handled by conventional container handling vehicles. For short-term storage the containers can be stacked two high when full and three high when empty. Normal operation will provide for loading 36 to 50 containers on 18 to 25 rail cars per transfer station per day.

Two solid waste unit trains per day will deliver up to 5,500 mt per day to the Labadie processing plant via two different railroads. Approximately 900 mt per day will be delivered to the Meramec process plant on a single unit train by one railroad.

PROCESSING FACILITIES

The SWUS is being designed to provide a nominal processing capacity of 6,000 tons (approximately 5,500 mt) per day at the West (Labadie) facility and 2,000 tons (approximately 1,800 mt) per day at the South (Meramec) facility. Maximum peak processing capability will be 9,600 tons per day (8,700 mt) at the west facility and 3,600 tons per day (3,300 mt) at the south facility. Both processing facilities will be able to accept truck-delivered solid waste.

Containers at the processing plants will be handled by container handling vehicles. Placed on container unloading frames, the containers will be unloaded by ground mounted telescoping cylinders which will operate the container ejection blade.

The west processing facility will include four processing lines, each having a capacity of 100 tons (90 mt) per hour. The south facility will include three lines. Each facility will have a redundant processing line to provide for hammermill maintenance. Figure 3 is the preliminary process flow diagram for the west facility.

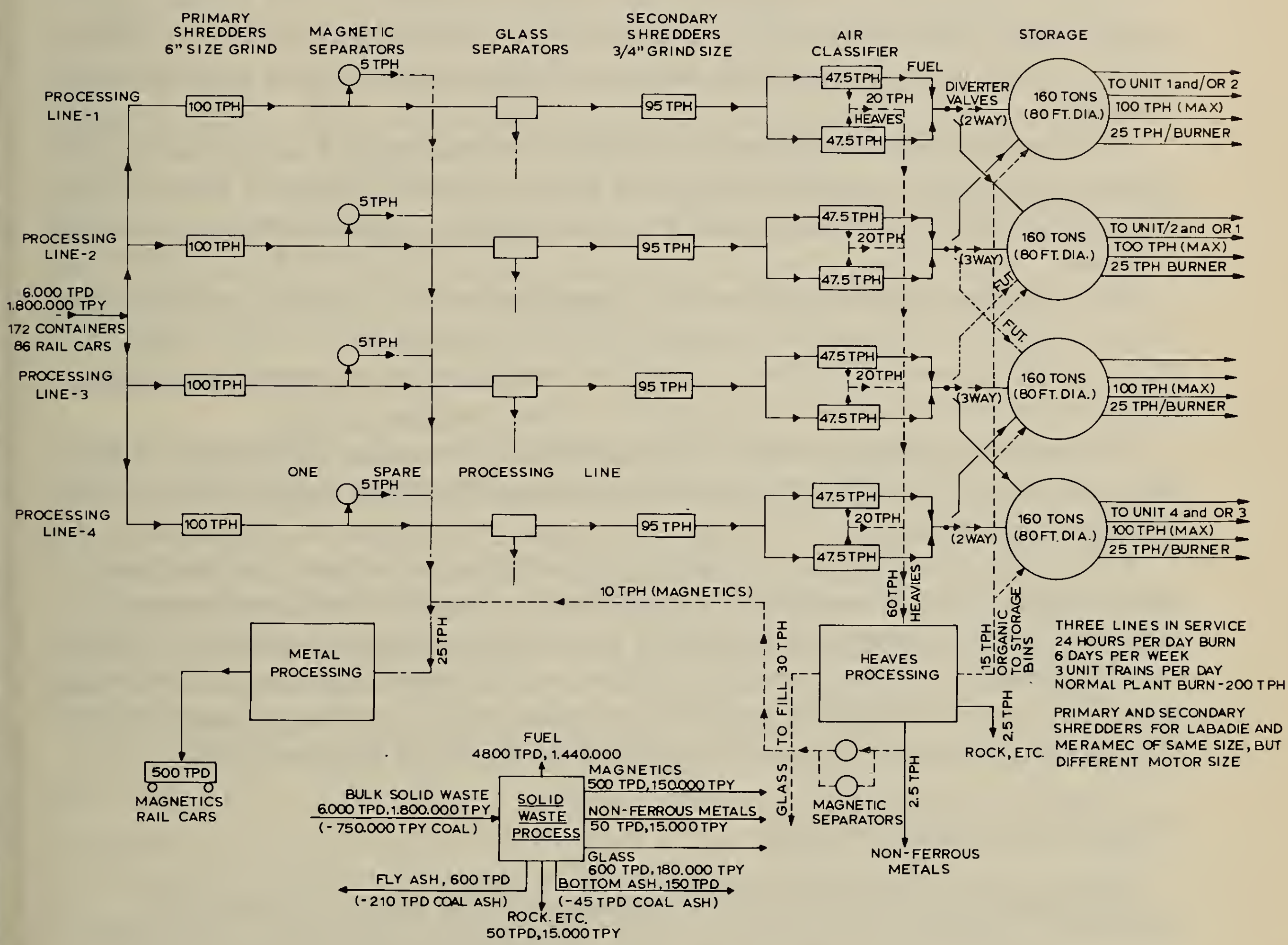

Fig. 3. Preliminary flow diagram for west process facility.

The first stage, reversible, auto shredder type, horizontal shaft hammermill will reduce the solid waste to a nominal 6-in. size. The first stage will be 2,000 hp (1.5 MW).

The first stage mill product will be conveyed to magnets for separation of magnetic metals. Both belt and drum magnets are being investigated.

The magnetic metals will be sold to a secondary metal processor for detinning and production of tin and No.1 bundle steel scrap.

The coarse milled waste, including less magnetic metals, will be conveyed to a glass removal device. This device has not yet been selected. Investigations have been underway for the past few months to develop a conveyor and sizing device. Such a device appears to be commercially available; it is expected to remove about 50 percent of the glass and grit.

The 1250 hp (0.9 MW) second stage, horizontal shaft hammermills will produce a 3/4 to 1 in. (1.9 to 2.5cm) product size. The mill discharge will be conveyed to air density separators for classification into burnable and unburnable fractions.

At the west facility, there will be two air classifiers for each of the four second stage mills, each with a capacity of 50 tons (45mt) per hour. The south facility second stage mills will each feed a single 50 tons per day air classifier.

The burnable fraction from the air classifier will be air transported to live bottom surge bins. At the west facility there will be 4 bins each with an outfeed capacity of 100 tons (91mt) per hour via four outfeed chutes, as shown in Fig.3.

The west facility surge bins will be equipped with 4 outfeed systems. Each outfeed system will include two drag chain conveyors set into the circular floor on 45° centers. The two conveyors feed into a common chute which feeds the solid waste into a pneumatic, boiler charging system.

The surge bins provide only limited storage. At a boiler firing rate of from 80 to 100 tons (73 to 90 mt) per hour there will be only from 1/2 to 1 hour storage in each bin.

At the south facility, the existing experimental prototype bin that has been in service three years will be modified to provide for higher capacity and will be direct current powered. A new four conveyor bin will be used to provide firing tc the two boilers at Meramec that were not used in the prototype. The south facility bins will be equipped with 4 outfeed conveyors and the new bin will have a capacity of about 60 tons (54 mt) per hour.

BOILER CHARGING SYSTEMS

The boilers at the south facility Meramec Power Plant include: two 140 MW, combustion engineering (CE), tangentially fired units; a 250 MW, Foster Wheeler , front-fired boiler; a 300 MW Foster Wheeler front fired boiler. All are fired with pulverized coal and are equipped with electrostatic precipitators.

The Meramec unit 1 and 2, CE boilers are presently equipped with 4 solid waste (SW) burners per boiler. These will be relocated to deliver the refuse-derived fuel just above the top level of coal burners. One SW burner will be located in each corner of the boiler furnace at the top of the coal burner assembly.

The SW burners for Meramec units 3 and 4 will be installed in the front wall of the furnace above the top row of coal burners. There will be four burners in unit 3 and four burners in unit 4.

The boilers at the west facility Labadie Plant include 4,600 MW, CE, tangentially fired, pulverized coal boilers. All are essentially identical. Each boiler will be equipped with 4 SW burners, one per corner. The burners will be installed just above the top coal burner in the coal burner assembly.

The boiler charging system for each burner consists of one rotary air feeder, positive displacement blower, and piping from the feeder to the boiler burner. The infeed chute to the rotary air lock feeder is fed from one or more surge bin conveyors.

Because the SW will contain residual ground glass and some metals the SW piping will be installed with removable wear-back elbows. Ceramic lined fiberglass pipe is currently being investigated for the straight sections of the transport piping. The ceramic lined pipe is considerably lighter than plain carbon steel pipe and appears to have good anti-abrasion characteristics.

The boiler charging system is being designed to provide up to 20 percent of the full load heat input requirement of each boiler. The 8,000 tons per day (7,300 mt) SWUS processing capacity can provide full firing at 10 percent of full load heat input. Thus, there is redundant boiler capacity.

SOLID WASTE CHARACTERISTICS

Table 1 gives the analyses for 380 samples of air-classified solid waste. Note that the figure for NaCl should be subtracted from the figure for total chlorides to give an analysis for organic chlorides. It is apparent that the refuse-derived fuel does not contain critical levels of organic chlorine (measured this way) which will be released during combustion (NaCl decomposes at 1650° C; furnace temperatures are of the order of 1370° to 1480° C). More than 75 percent of the chlorine in refuse-derived fuel can be accounted for as NaCl. The analytical methods have been described [2].

The density of the refuse-derived fuel after milling to 1.9 cm varies from 64 to 112 kg/m^3 (4 to 7 $lb./ft.^3$), loose. However, when placed in storage to depths of from 9 to 12 m (30 to 40 ft.), the density increases to as high as 400 kg/m^3 (25 $lb./ft.^3$). Moisture content and particle size have a significant effect on density and flow characteristics and these characteristics vary from day to day and through the system.

ENVIRONMENTAL IMPACT

Careful evaluation of the environmental impact of the SWUS has been underway since initial operation of the prototype. Boiler gas emission tests conducted independently by the U.S. Environmental Protection Agency and Union Electric during November and December of 1973 disclosed no serious emission problems.

Certainly when compared to disposal by landfill or incineration the SWUS appears to offer significant advantages. Conservation by recycling metal resources such as tin, steel, copper, and aluminum offers a significant environmental advantage over disposal.

TABLE 1

Air-classified refuse analyses[a]
380 samples taken November 9, 1973 through December 10, 1974

As fired basis

	Moisture (wt %)	Ash (wt %)	Sulfur (wt %)	Total chlorides (wt %)	NaCl[b] (wt %)	J/kg $\times 10^{-6}$
Average	27.5	18.5	0.11	0.34	0.27	11.6
Maximum	63.0	53.8	0.31	0.94	0.59	17.7
Minimum	3.0	7.6	0.02	0.13	0.10	5.3

Air-classified refuse ash (wt %)

	Average	Maximum	Minimum
P_2O_5	1.32	2.04	0.41
SiO_2	52.8	66.6	39.9
Al_2O_3	9.71	26.90	3.43
TiO_2	0.89	1.79	0.07
Fe_2O_3	6.40	22.19	2.57
CaO	12.06	16.50	6.92
MgO	1.48	3.17	0.22
SO_3	1.55	3.75	0.54
K_2O	1.68	2.91	0.89
Na_2O	8.22	19.20	3.11
SnO_2	0.034	0.10	0.001
CuO	0.21	1.74	0.03
ZnO	0.34	2.25	0.09
PbO	0.19	0.73	0.04

[a] Analyses by "Research 900" Division of Ralston Purina Company, St. Louis, Mo.
[b] NaCl percentage is subtractable from total chlorides.

ECONOMICS

The SWUS is being built as a free enterprise, profit making venture. The risk capital to build the system will come from private investors. The SWUS must attract the public and private haulers by offering a dumping service at lower overall cost than any competing service.

The economics of scale, low unit train point-to-point rail transport costs, sale of metals, and the sale of the burnable fraction of the solid waste will provide the revenue to support the investment.

CONCLUSION

The SWUS is expected to provide an environmentally sound economic system to utilize the materials available in the solid waste stream. It will significantly reduce the water, air, and esthetic degradation of the environment which is too often a product of poorly managed landfills. SWUS will provide for conservation of irreplaceable fossil fuels and metals, and it will provide these benefits within the framework of the free enterprise system.

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Resource Recovery and Conservation, 1 (1976) 235—243

DESIGN AND POLLUTION CONTROL FEATURES OF THE SAUGUS, MASSACHUSETTS STEAM GENERATING REFUSE—ENERGY PLANT*

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INTRODUCTION

A steam generating plant using refuse for fuel is being constructed at Saugus, Massachusetts which, on completion, will dispose of an average of 1,089 metric tons (1,200 tons) of refuse a day from some 16 communities north of Boston and provide energy to a nearby industrial plant for electric power generation and process steam. The system is an application of the Von Roll type water tube cooled boiler system with stepped grates, firing refuse essentially as received without the use of auxiliary fuel. Several recently developed features are incorporated in the design to improve reliability and availability under the relatively high steam temperatures involved. The plant is constructed to meet stringent pollution control standards for odor, particulates, gas, noise and water emission, and will provide essentially complete refuse combustion without the need for auxiliary fuels. Clean metals and sterile ash suitable for road fill will be recovered initially and provision is being made for expansion of materials recovery sub-systems in the future as markets and technology make them economically viable. The design also contemplates future doubling of all plant capacity to 2,177 metric tons (2,400 tons) per day.

An unusual feature of the plant is that it is privately financed, owned and operated and will pay real estate and income taxes. Severe requirements for continuity and reliability of refuse acceptance have been imposed, since the landfill currently available to the communities will be permanently closed for environmental reasons as soon as the plant goes into operation. In addition, the demand for continuity of steam generating capability emphasizes reliability in the system design and calls for the provisions of adequate standby facilities.

Ground was broken for the Saugus refuse energy plant in June 1973, with initial operation scheduled for mid-1975. The 16 communities, with a com-

*Paper presented at the Symposium "Energy Recovery from Solid Waste", March 13—14, 1975.

bined population of approximately 500,000, are expected to make their own arrangements for refuse delivery to the plant weighing station and will pay a tonnage fee for disposal. Complete and sanitary combustion of the refuse will produce more than 900,000 metric ton of steam a year for sale to the General Electric Company (GE) manufacturing plant at Lynn, Massachusetts, across the Saugus River. This energy sale will help reduce disposal charges to the communities and at the same time reduce fuel oil requirements by approximately 260,000 liters (70,000 gallons) a day. It is significant that a net improvement in air pollution conditions will result, since the sulfur and particulate emission from the refuse plant will be even lower than for the facilities being replaced which burn low sulfur fuel oil.

BACKGROUND

The need to provide a modern and clean refuse disposal system became apparent in the Boston North Shore area when state environmental and other requirements resulted in a court order to close down a large sanitary landfill operation in the tidelands at Saugus, Massachusetts serving the area communities.

The project is privately financed, owned and to be operated by the Refuse Energy Systems Company (RESCO), a joint venture of Wheelabrator-Frye Inc. and M. DeMatteo Construction. The system design and construction management is being carried out by Rust Engineering Company of Birmingham, Alabama, a subsidiary of Wheelabrator-Frye, and construction is being undertaken by DeMatteo Construction. The plant design concept is based on Wheelabrator's exclusive license with Von Roll, Limited of Switzerland and is an updated version of, and similar in operation to other Von Roll refuse-energy plants in Europe, Australia, Japan and Canada. In the Saugus situation, however, it meets generally more severe environmental requirements, makes use of several new features involving advanced technology, and meets a number of specialized demands imposed by site conditions and unusual requirements for reliability and continuity of refuse acceptance and steam production [1].

Low operating cost over the life of the plant is considered essential as a protection against inflation. The estimated total initial capital cost of approximately $30 million for the plant recognizes these requirements and special conditions and includes land, maintenance shops, roads, weighing stations, vehicles, spare parts, utilities bridge and a 0.8 kilometer pipe line system extending across the Saugus River for steam delivery, condensate return and electric power.

SPECIAL REQUIREMENTS

As noted previously, there are a number of unusual conditions and requirements placed on the design of the plant and reflected in the cost. These can be summarized as follows:

— The present landfill site has been ordered closed and cannot continue in operation after plant completion. For this reason an unusually large storage pit (6,100 metric tons capacity) is provided to accumulate refuse during shutdown of a boiler for maintenance or repairs.

— Since the plant is constructed on the landfill, the site conditions are poor, requiring all major structures to be supported by piles driven to bedrock, some 24 meters below.

— The communities prefer a single type of collection as a cost saving measure. As a result, minimum selectivity will be exercised at the plant in accepting refuse and garbage, provided it has domestic or commercial origin. Stoves, tires, mufflers, furniture, auto wheels, pipes, etc. will be taken as normally present in municipal refuse.

— The steam delivery contract to GE requires not only standby oil jets in the main boilers, but also two auxiliary standby oil fired boilers.

— No intake or discharge is permitted to the river.

— A utility bridge and pipe line system is required to transmit steam across the Saugus River.

— Local air pollution control requirements are more stringent than Federal standards.

BASIC REQUIREMENTS

The basic requirements are to accept an average of 1,089 metric tons per day of domestic and commercial refuse and provide steam to the General Electric Company at 4,309 kPa (625 psig) and 418—441°C (785—825°F). These steam conditions were selected to coordinate with the output of existing boilers in the GE plant [2]. Operation is 24 hours a day, 7 days a week. Peak steam delivery is 159 metric tons per hour and not les than 29.5 metric tons per hour. A minimum of 90,000 metric tons of steam will be delivered annually.

A dump charge will be made with escalation corresponding to half the change in the local labor wage index. Steam charges are based on providing somewhat lower energy cost to GE than would be involved if oil were used as a fuel. Steam charges will escalate with oil price increases.

SYSTEM DESCRIPTION

The physical layout of the plant and its geographical proximity to the steam customer is illustrated in Fig. 1. Refuse trucks will pass a weighing station and move up a paved earthfill ramp to a receiving area. Here the trucks are backed to the plant entrance doors and refuse is deposited in the 6,100 metric ton-capacity pit.

A simplified cross section of the plant is shown in Fig. 2. In general configuration this is similar to other refuse boiler plants except for the stepped grates and the pendant, vertically oriented tubes in the convection section.

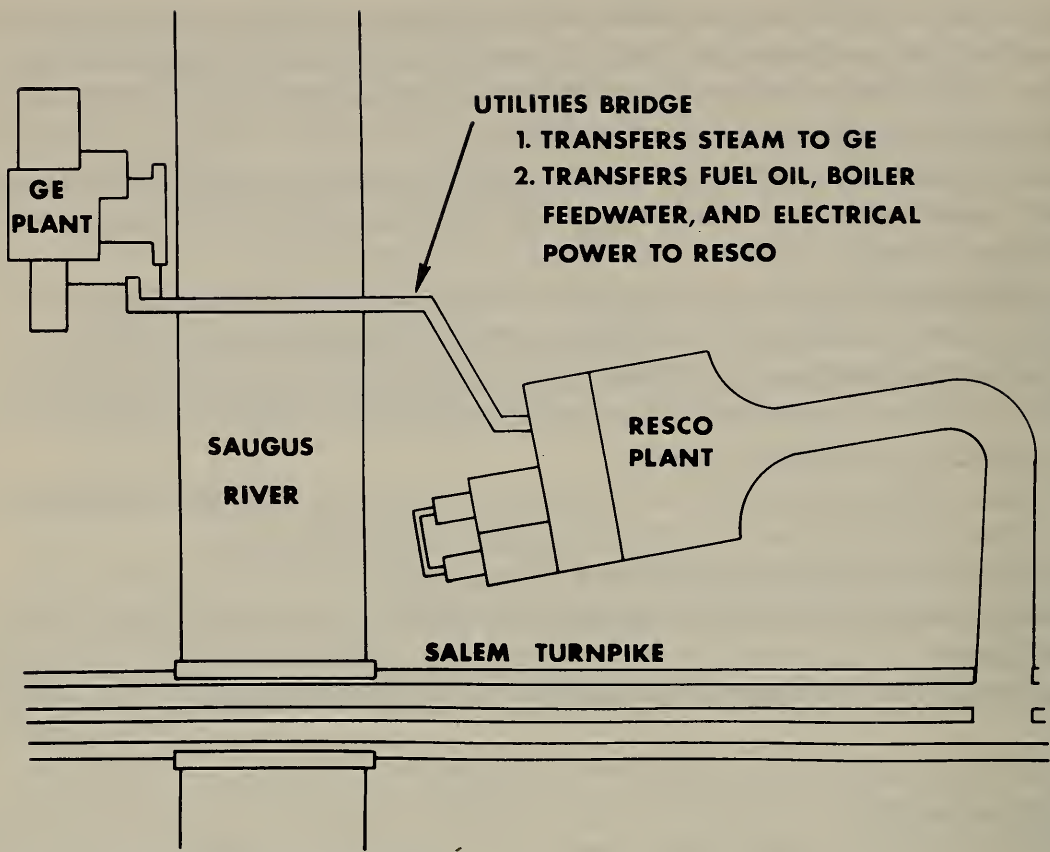

Fig. 1. Physical layout of RESCO.

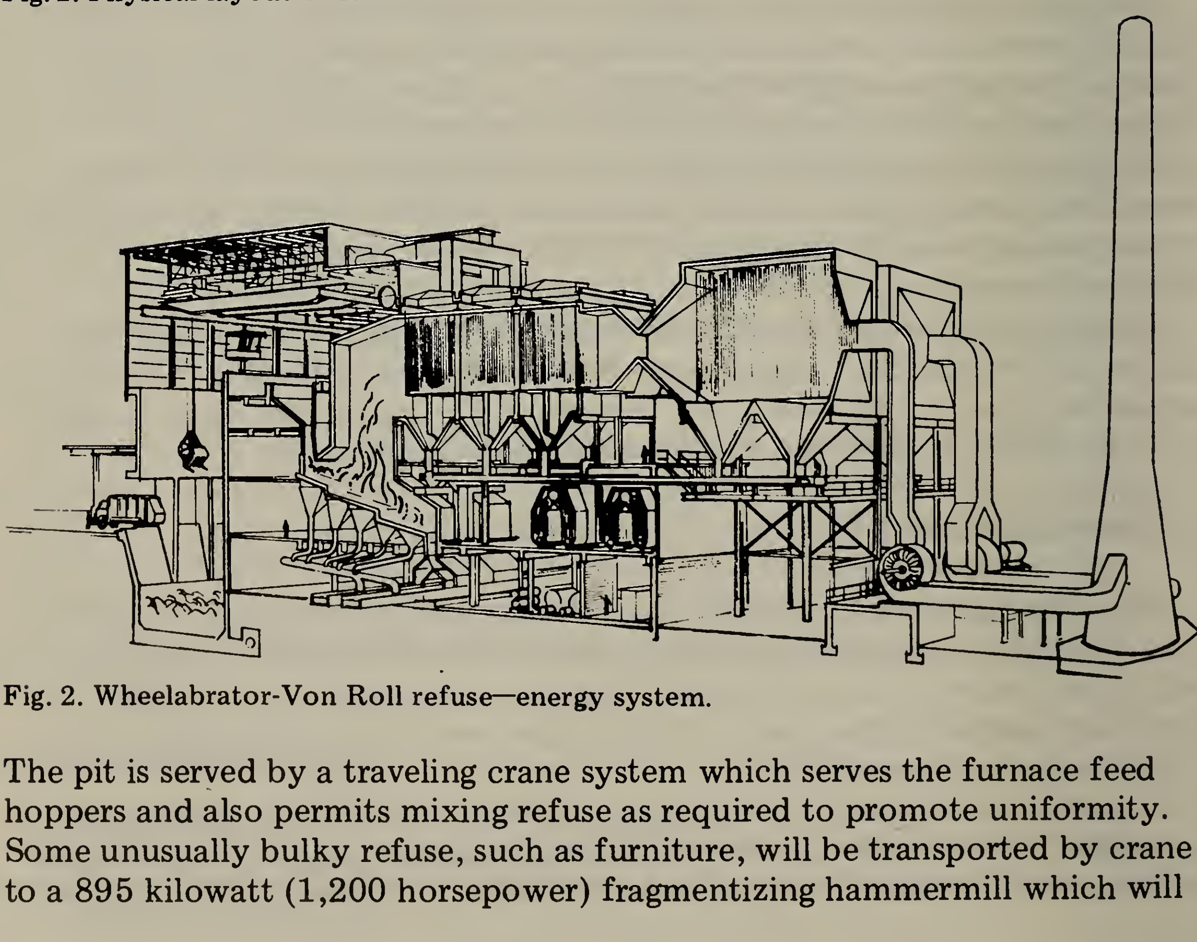

Fig. 2. Wheelabrator-Von Roll refuse—energy system.

The pit is served by a traveling crane system which serves the furnace feed hoppers and also permits mixing refuse as required to promote uniformity. Some unusually bulky refuse, such as furniture, will be transported by crane to a 895 kilowatt (1,200 horsepower) fragmentizing hammermill which will reduce the largest dimension to about 0.3 meters and discharge the fragments back into the pit.

Two steam generators are provided initially, with a maximum capacity of 680 metric tons per day each, for refuse with a heat value of 10.5 MJ/kg (4,500 BTU/lb.), Lower Heating Value. Provision is made for the addition of two similar boilers at a later date. Two oil fired package boilers are also provided as standby units with a total capacity of 108.9 metric tons per hour. In each furnace, refuse is burned on a Wheelabrator/Von Roll reciprocating grate system without the use of an auxiliary fuel. This consists of three grates separated by steps over which refuse tumbles to provide complete combustion. Combustion gas temperatures are in the range of 540—980°C. Under-fire and over-fire air volume and temperature as well as individual grate operating speeds are controlled to suit conditions and assure complete burnout. Much of this control is automatic.

The flue gas and furnace radiation heats the water walls of the boiler. Heated flue gases then pass through the convection section and come in contact with pendant boiler tubes. Dust and scale buildup is controlled by a specially designed boiler tube rapping mechanism. The system involves periodic striking of the lower side of vertical boiler tube sections with a hammer mechanism. Such operation dislodges dust buildup on the tubes without disturbing the protective oxide coating on the tube exterior. This recent development eliminates corrosion problems from soot blowers and makes it unnecessary to shut down the boilers for periodic tube cleaning. The cooled gases pass to two Wheelabrator-Lurgi electrostatic precipitators [3], operating at approximately 99 percent efficiency, designed to reduce the particulate emission to 5.7×10^{-4} kg/m^3 (0.025 grams/standard cubic foot) corrected to 12 percent CO_2 (0.05 required). These are described in more detail later in the section covering pollution control. Cleaned exit flue gas is discharged to the atmosphere through a concrete stack 54.3 meters (178 feet) above grade.

Fly ash collected by the precipitators, riddlings and clinkers are water quenched and passed by conveyor to a rotating screen. Bulky metals are separated for sale and the bottom ash screenings are further subjected to magnetic separation. This permits sale of the remaining ferrous metals. The residual ash (about 160 metric tons per day) will be sold or used as road fill or deposited in a specially designated disposal area nearby. Quench water is discharged in wet ash or evaporated. Blowdown water is almost entirely consumed by transfer to the quench tanks.

FINANCING

Initial financing was arranged through Wheelabrator Financial Corporation, a subsidiary of Wheelabrator-Frye. This financing of the plant construction is not contingent on any signing of refuse disposal contracts with the municipalities. Subsequent debt financing is being arranged through tax exempt industrial revenue bonds.

ESTABLISHMENT OF DUMP CHARGES

Dump charges, or so-called tipping fees, are based on individual agreements with municipalities. It is contemplated that initial charges will be lower for longer term contracts and that escalation of rates will be based on one half the rate of change in the local labor rate index. RESCO has joined a number of the communities in obtaining the services of the Mitre Corporation, a not-for-profit corporation headquartered at Bedford, Massachusetts, to examine the costs of the project and to determine the appropriateness of the proposed charges, considering costs and risks. This has resulted in a contract structure and pricing schedule adjudged fair to all concerned.

TECHNOLOGY

The RESCO project is designed to make use of updated technology applied to established concepts proven by full scale experience in similar situations. The importance of reliability, continuity in refuse disposal, pollution control and steam generation were the principal factors in utilizing the total combustion system concept supported by substantial experience in Europe, Canada and Japan. No wholesale shredding of refuse is required, thus saving shredding costs estimated in excess of $3.00 per ton and eliminating fire and explosion problems [4—6].

The 5.3-hectare (13-acre) site and plant layout has been arranged for maximum flexibility and to permit future construction of additional resource recovery subsystems, either at the front end or back end of the energy recovery unit when and if the technology, economics, experience and market shows this to be a viable and reliable operation.

POLLUTION CONTROL DESIGN

Odor control

Odor control was an important consideration in both the construction and operation of the Saugus plant. Since the facility is being built on a sanitary landfill site covered by a layer of deposited refuse approximately 3.7 meters (12 feet) thick, unusual measures had to be adopted during excavation for the plant foundations and truck receiving area. A total of approximately 46,000 cubic meters of refuse material had to be removed to another area in the existing landfill and covered daily with a layer of earth. Deodorizing units, consisting of 19 liter (5 gallon) pails equipped with wicks and filled with Air Kem water soluble deodorizing fluid, were placed at intervals of about 15 meters to the windward side of the removal operation. Earth fill was placed in the excavation in a concurrent operation to minimize exposure. These procedures were carried out under permission and inspection of the Massachusetts Bureau of Air Quality Control.

Refuse odors during plant operations will be closely controlled by dumping all refuse into the indoor storage pit. A system of negative pressure will draw fresh air through the entrance into the pit enclosure from which it is drawn into the furnaces for use as combustion air. Furnace gas temperatures are maintained in the range of approximately 540—980°C, destroying odors in the combustion air and those emitted by burning refuse. The main control room, administrative space and crane operator consoles are enclosed and air conditioned to produce a temperature and odor controlled environment.

Control of particulates

Fly ash and particulates in the flue gas will be reduced well below levels specified by federal, state and local requirements. This is accomplished by means of collection hoppers under the boiler convection sections, followed by Wheelabrator-Lurgi electrostatic precipitators. Precipitators were chosen in place of wet scrubbers for reliability and to minimize generation of a steam plume from the stack caused by introduction of additional moisture. An individual, dry bottom precipitator is provided for each steam generating unit. Each will handle 6,800 cubic meters per minute of flue gas at 220°C to surpass the stringent Metropolitan Boston Air Pollution Control District requirements of 11.4×10^{-4} kg/m^3 (0.05 gr/scf), corrected to 12 percent CO_2. The precipitators are designed to control particulates to 5.7×10^{-4} kg/m^3 (0.025 gr/scf) and, therefore, are sized to operate at an efficiency of approximately 99 percent.

The reliability and continuous availability of the precipitator units are enhanced by employing discharge electrode rods welded into rectangular pipe frames in such a manner that the electrodes are firmly attached at points separated by no more than 1.5 meters. The rigid support system was considered to offer advantages over a system using weighted hanging wires by providing improved strength and controlling electrode failure due to material fatigue, corrosion or oscillation. Any additional cost was considered to be outweighed by advantages from the standpoint of maintenance and continuity of operation.

Air quality

Since refuse is a low sulfur fuel, typically with only about 0.1 percent sulfur content, no special measures will be required to remove this component. To fully disperse the exit gases, which consist almost entirely of nitrogen, carbon dioxide and water vapor, a 54 meter (178 foot) concrete stack is being employed, 2.7 meters (9 feet) in diameter at the top. No problems with chloride emission are foreseen, based on experience with similar installations [7]. Flame temperatures are kept below the level at which nitrogen oxides would be produced in any significant quantity. Based on experience with similar installations, these emissions are expected to be much lower than the

0.13 kg/10^9 J (0.3 pound/10^6 BTU) input permissible for liquid fossil fuel fired systems. Because the standby oil fired boilers are planned to be operated on low sulfur oil when no refuse is available, and will meet emission requirements, permission has been obtained to exhaust through smaller stacks extending over the roof, approximately 38 meters above ground level. Smoke density requirement of less than Ringelmann No. 1 will be met.

Ambient particulate levels have been calculated using Weather Bureau data and predicted emissions from the stack, using a computer program developed by Rust Engineering on the basis of ASME procedures. Predictions for one-hour concentrations under least favorable conditions indicated that the addition of the stack emissions to existing annual averages would not exceed the allowable value of 75 micrograms per cubic meter. Actually, operation of the refuse-energy plant should produce no net impairment to the average ambient level since this includes the GE plant present emissions, which will be reduced when the refuse plant becomes operational.

Water quality

Water for steam production, cooling, and ash quenching will be obtained from the municipal supply in addition to that needed for the sanitary system. Some steam condensate is to be returned over the utility bridge and optimum recirculation and treatment is provided to minimize input water requirements and effluent discharge. No river water will be circulated or used.

Waste water sources are the sanitary system, boiler blowdown, demineralizer backwash, and quench channel overflow. All blowdown and backwash, neutralized as required, is pumped to a holding tank which feeds the ash quench conveyor channels. No ash quench water is recirculated since it is progressively removed in the wet ash with overflow to the sewer. Under operating conditions, total flow to the sewer is expected to consist primarily of the sanitary system discharge.

Noise control

Most of the machinery that would make any appreciable contribution to the noise level in the area of the plant is housed within the plant buildings. The exceptions are the refuse boiler I.D. fans which are located between the precipitators and the stack and the trommel screens located in the ash handling system.

An ambient noise level survey was performed prior to the start of construction, and calculations have been prepared to show anticipated noise levels when the plant is in operation. Application for permits have been filed, and it is anticipated that the plant will meet all necessary requirements.

CONCLUSION

Unusual construction conditions and the need to provide essentially un-interrupted availability of refuse reception, control of pollution and steam generating capacity has resulted in specialized adaptations in the design and pollution control measures for the Saugus Refuse Energy System. It should provide an example of a multi-community refuse disposal service operated in an environmentally sound manner on a private enterprise basis and privately financed. Significant and important elements of the system plan included the cooperation of a large industrial energy user and the decision to employ a design based on demonstrated concepts with minimum preprocessing and selectivity of refuse input.

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AN EVALUATION OF METHANE PRODUCTION FROM SOLID WASTE*

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ABSTRACT

A technical and economic evaluation of a process to convert municipal solid waste to a pipeline quality gas has been carried out, based upon a previously reported conceptual design for a 907 metric ton/day (1000 tpd) facility. The process design is shown to be technically within the state of the art, although economically acceptable operating parameters are at the upper limit of today's technology. The calculated baseline gas cost of $0.074/m^3 ($2.09/mcf) is economically acceptable when compared with projected costs of synthetic gas or alternative fuels. Experimental priorities to demonstrate the commercial feasibility of the process are established.

INTRODUCTION

Because of the two problems of need for supplemental sources of fuel gas and concern about municipal waste disposal, considerable interest has recently been shown in the related solution of applying anaerobic digestion to municipal solid wastes. The digestion of the organic matter in municipal refuse can be carried out much as the digestion of sewage sludge is done. The organic matter in typical solid waste is observed to be predominantly cellulose; therefore, the chemical conversion and stoichiometry of concern may be represented by

$$C_6H_{10}O_5 + H_2O \rightarrow 3\ CO_2 + 3\ CH_4 \quad (1)$$

In the process for preparing methane from municipal waste, the organic material is slurried with water and inoculated with the proper microorganisms. This inoculation is spontaneous in an operating digester since organisms are already present. The organic matter is partially solubilized or digested and then fermented, forming methane gas, carbon dioxide and a residue of undigested material. Under these circumstances 1 kg of chemically convertible waste will yield 0.41 m^3 (1 lb → 6.65 $ft.^3$) of methane at standard conditions of temperature and pressure [1]. The methane will be accompanied by an equal volume of carbon dioxide. The methane is scrubbed free of carbon dioxide

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and traces of hydrogen sulfide, then dried. The undigested residue is disposed of by incineration or landfill. Ferrous and non-ferrous metals and glass may be recovered prior to digestion, if that is economical.

Previous studies have focused attention on the scientific and the economic feasibility of the process, and the conceptual design of a 907 metric ton/day (1000 tpd) facility [2—8]. It is presently projected that pipeline-quality gas can be produced commercially with a selling price of $0.074/m^3 ($2.09/mcf), based on an American Gas Association public utility financing scheme (Table 1) [9, 10]. An evaluation of the energy balance indicates that operating energy requirements consume the equivalent of only 37.5 percent of the gas produced [2].

TABLE 1

Summary of base-line gas cost items

	\$/m^3	\$/mcf
Contribution of capital costs to gas cost	\$ 0.076	\$ 2.17
Contribution of operating costs to gas cost	0.069	1.92
Penalties:		
Filter cake (\$30/dry ton)	0.055	1.55
Waste water from filter (\$1.00/1000 gallons)	0.001	0.03
Waste rejected by trommel screen and air classifier (\$3.50/ton)	0.009	0.26
Credits:		
Fresh waste (\$10.65/ton)	(0.102)	2.87
Sewage sludge (\$50/dry ton)	(0.018)	0.51
Scrap iron (\$25/ton)	(0.016)	0.46
	\$ 0.074/m^3	\$ 2.09/mcf

EVALUATION OF THE PROCESS

There can be little doubt that the investigation of fuel gas production from solid waste is both timely and significant. Fuel gas production from solid waste appears to offer at least a partial solution to the search for alternative energy sources, particularly for natural gas. In addition, the technology and operating experience gained from this process have direct application to other promising bioconversion concepts.

Process design

The conceptual process design proposed for fuel gas production from solid waste, Fig.1, does not appear to require the development of any new technology to construct a commercial-scale facility. On the other hand, an extensive background of bench- and pilot-scale data which would permit the

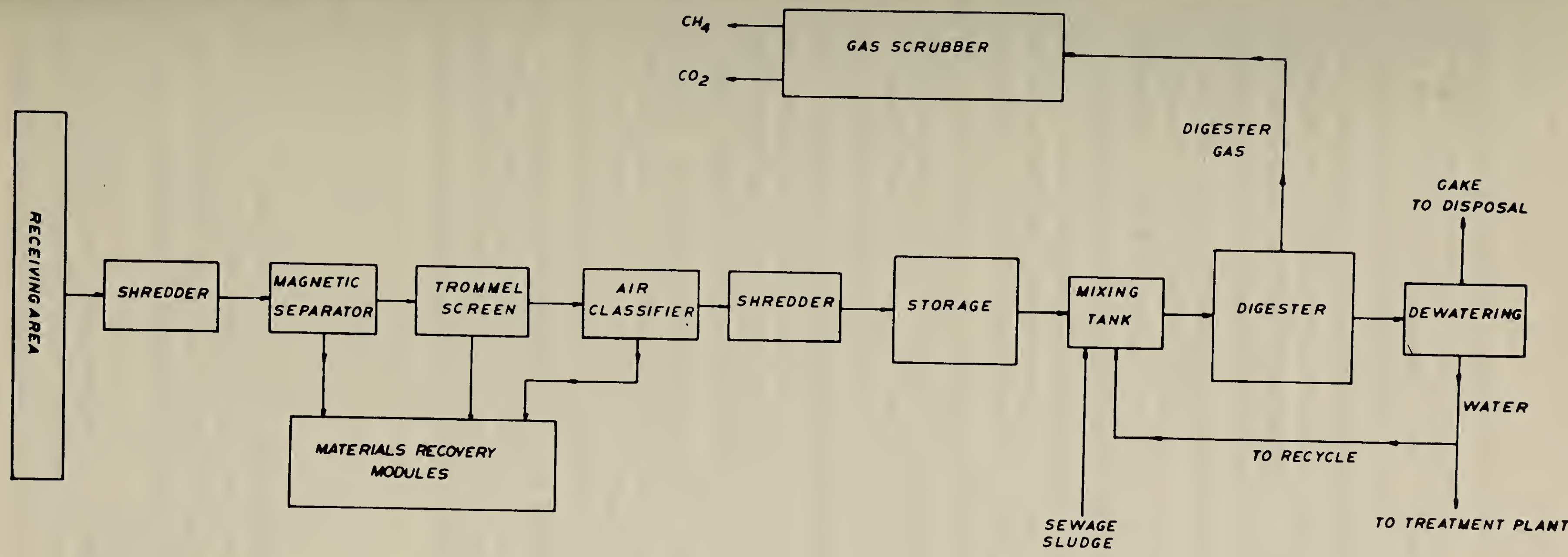

Fig.1. Flow sheet of anaerobic digestion process for solid waste utilization.

confident design and prediction of performance of a full-scale operating plant is presently unavailable.

The design of the feed preparation system is based upon the current state-of-the-art of commercially available equipment. Most of the components selected have had previous application in mineral processing or pulp and paper manufacture. The mechanical performance and reliability of each component has been extensively proven in these fields, but application to solid waste is somewhat limited. For example, production-scale air classification of shredded municipal waste has only recently been accomplished. As more facilities come on-line, additional operating data will become available which will permit an optimization of the feed preparation system design. Fifteen major resource recovery plants are expected to be on-line throughout the United States by 1976 [11]. In addition, numerous publicly and privately funded research projects are underway which should provide valuable operating data for further optimization of the feed preparation design. However, few of these projects may be expected to concentrate on the preparation of a high-purity cellulosic fraction suitable for anaerobic digestion, and none will examine the interface between the feed preparation and digestion systems.

Many questions remain to be answered with respect to the design of the backend of the system. The most important question pertains to the maximum permissible volatile solids loading for the anaerobic digesters. The volatile solids feed concentration and the solids retention time selected by analysis to produce a minimum gas cost result in a volatile solids loading to the digesters near the upper limit of that normally encountered in sewage sludge digesters. None of the experimental data published to date for solid waste digesters deals with performance under these operating conditions. Discussions with equipment manufacturers indicate that the assumed solids concentrations in the digester feed and effluent are also near the upper limit of that normally handled with the type of equipment proposed for pumping, mixing and dewatering. As is the case for the feed preparation equipment, process operating data are currently not available relating to various performance characteristics in such a manner as to permit optimization of the process. Experiments to date have not been run at a sufficiently large scale to gather the type of data necessary.

Process ecnomics

The projected economics for the 907 metric ton/day fuel gas from solid waste facility should be evaluated from two standpoints. First of all, do the projected economics accurately represent those to be expected from a commercial facility? Secondly, are the projected economics acceptable to the user community and the gas consumer?

The projected economics are judged to be representative. Capital costs have been determined from equipment manufacturer's quotations, from engineering estimates developed by consulting engineering firms for similar installations, and from published, historical data. Where multiple quotes were available, capital costs were chosen to represent what was judged to be the best available equipment from the standpoint of performance. Capital costs, therefore, tend towards the conservative side. All costs have been escalated to uniform (June, 1974) construction costs using the Engineering News Record (ENR) Construction Cost Index. Costs of installation and auxilliary equipment have been included. The American Gas Association public utility cost accounting structure used considers the associated costs of debt and equity capital as well as operating costs [9]. It must be emphasized that while the economics are representative of those realistically expected from a commercial-scale facility, performance at the levels required has not yet been consistently demonstrated in the laboratory.

The projected net gas cost is judged to be acceptable. The economic analysis indicates that, under baseline operating conditions, the net cost of gas will be in the range of \$0.028 to \$0.097/m^3 (\$0.75—\$2.75/mcf), depending upon the ownership option selected for the plant and the cost of debt and equity capital. Based upon figures published in the latest edition of Brown's Directory of North American Gas Companies, the average revenue for interstate gas sales was \$0.028/m^3 (\$0.75/mcf)[12]. At that time, the average price paid producers was \$0.007/m^3 (\$0.21/mcf) at the well head. The Federal Power Commission (FPC) has proposed an increase to \$0.009/m^3 (\$0.245/mcf) for "old" gas [13]. "New" gas, from wells commenced on or after January 1, 1973, has recently been priced at \$0.018/m^3 (\$0.50/mcf) by the FPC, with annual increases of \$0.0035/m^3 (\$0.01/mcf) allowed [14]. Intrastate gas sales, which are not regulated by the FPC, have reached \$0.057/m^3 (\$1.60/mcf) or more [15]. Prices for other supplemental sources of natural gas are even higher. Imported natural gas from British Columbia is presently set at \$0.035/m^3 (\$1.00/mcf) with annual \$0.007/m^3 (\$0.20/mcf) increases set for each of the next three years [16]. Imported liquefied natural gas from Algeria is estimated to have a landed cost of \$0.07/m^3 (\$2.00/mcf) [17]. Synthetic natural gas from naphtha and coal is estimated at \$0.070—\$0.088/m^3 (\$2.00—\$2.50/mcf)[18]. To each of these prices, an increment equivalent to the pipeline transmission cost must be added to yield a cost equivalent to the bioconversion process.

An appropriate comparison may be made with other energy sources. A study conducted by the FPC showed that steam electric generating plants were paying \$0.412/G J (\$0.436/MM Btu) for natural gas, \$0.61/G J (\$0.64/MM Btu) for coal and \$0.76/G J (\$1.87/MM Btu) for oil, based on April 1974 prices [19]. A further evaluation of current oil prices is revealing. "Old" oil is priced by the Federal Energy Administration at \$4.25/bbl (1 bbl = 159 liters), or \$0.825/G J (\$0.875/MM Btu) [20]. "New" domestic oil may follow the market and is priced at \$10—12/bbl. Imported crude oil from the Middle East is currently priced at \$11.63/bbl and crude from Venezuela is priced at \$14.43/bbl [13]. Methane produced from solid waste appears to be competitive with these prices. The gas produced from a privately owned and financed fuel gas from solid waste facility at \$0.075/m^3 (\$2.09/mcf) has an energy equivalent price of approximately \$11.00/bbl of crude oil.

Potential impact

The potential for a process which converts refuse to methane is significant. Residential and commercial refuse is produced at a rate of 1.4—2.3 kg (3—5 lb.) per person per day. At 4 lb./person/day, a 907 metric ton/day facility would service a population of approximately 500,000 people. According to the 1970 U.S. Census, there were 26 cities in the country with populations in excess of 500,000. More significantly, there are 65 Standard Metropolitan Statistical Areas (SMSA's) in the U.S. with populations in excess of 500,000. The aggregate population of these SMSA's is in excess of 100,000,000 — half of the nation's population. In terms of a 907 metric ton/day solid waste to methane facility, there is a potential market for over 200 plants in the urban areas of the United States.

A 907 metric ton/day bioconversion facility will produce approximately 105,000 m^3 (3.7 million ft.^{3}) of methane per day, or 0.21 m^3 (7.4 ft.^{3}) of methane per person. The 65 SMSA's with populations in excess of 500,000 have a potential for gas production from waste in excess of 21,225,000 m^3 (750,000,000 ft.^{3}) per day. Based on published figures [21], this process, if implemented in these 65 SMSA's, could produce approximately 1.5% of the total natural gas consumed in the United States. In order to identify further those regions of the country in which fuel gas production from solid waste could have significant impact, this study has been extended to each of these major SMSA's. The population of each was determined from the latest U.S. Census (1970). Potential gas production from each SMSA was determined based on an average daily production of 0.21 m^3 of methane per person. Actual gas consumption in each SMSA was estimated based upon figures published in Brown's Directory of North American Gas Companies [22]. Because gas-consumption figures were not usually broken down by SMSA, estimates were developed based upon the ratio of customers within the SMSA to the total number of customers served by each gas company within the SMSA. On average, approximately 9 percent of the gas consumed in these SMSA's could potentially be produced by the municipal solid waste generated by their residents. The median ratio of potential production to estimated consumption was 4 percent. A geographic evaluation of these results shows that these plants would have the greatest impact along the Boston-Washington corridor, an area highly dependent upon imported energy (Fig.2).

Figure 3 depicts the dramatic need for the additional fuel gas which could be produced from solid waste. Interstate pipeline curtailments for firm contract gas have been estimated for the five winter months — November, 1974 to March, 1975 — by the Federal Power Commission and the American Gas Association. The potential gas production from these 65 major SMSA's

Fig.2. SMSA's of greatest potential impact. • SMSA's where more than 6% of annual gas consumption may be produced from refuse.

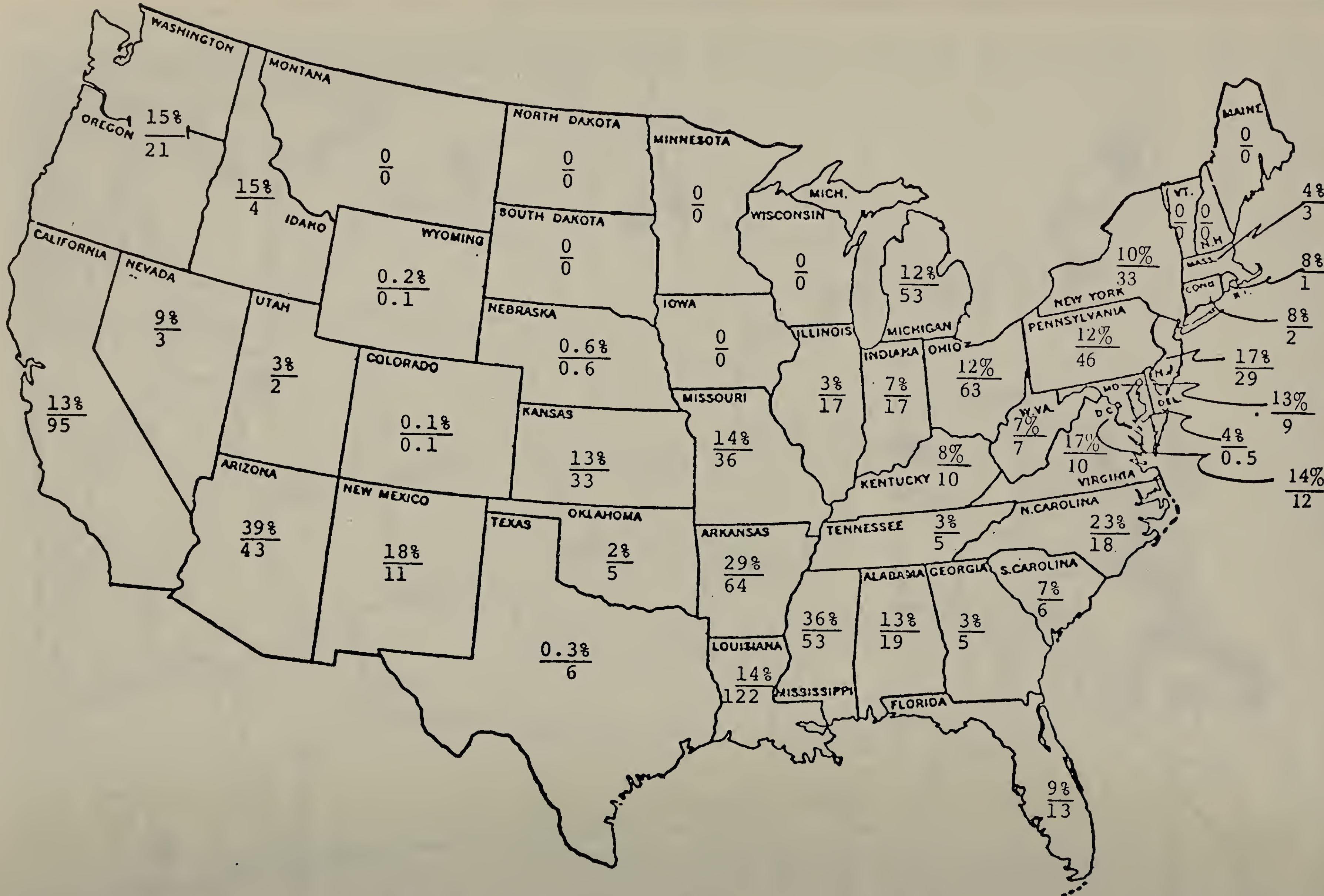

Fig. 3. Estimated interstate pipeline curtailments for firm contract gas, Nov., 1974 to March, 1975. (Oct. 22, 1974; revised Nov. 19, 1974). All interstate gas figures — no intrastate. 3%/5 indicates estimated interstate firm contract curtailments are 3% of state requirements for the winter period, and that volume curtailed is 5 billion ft.^{3}. (Sources: FPC data of Oct. 4, 1974, plus AGA estimates where FPC data are not available).

TABLE 2

Experimental matrix — program priorities

	Necessary to prove concept		Necessary to prepare full-scale design	Priority rank
	Technical	Economics		
Feed preparation				
Demonstrate capability to provide required digester feed	X	X	X	9
Determine sequence of operations			X	13
Determine primary shredder output size		X	X	15
Determine secondary shredder output size		X	X	16
Determine trommel screen opening		X	X	14
Confirm separation efficiencies		X	X	10
Establish character of daily and seasonal variations		X	X	17
Determine properties of residual materials		X	X	19
Digestion				
Confirm and demonstrate digester performance	X	X	X	1
Obtain continuous operating data at highest possible total volatile solids feed		X	X	11
Demonstrate effective digester performance when solids retention time is optimized with respect to over-all process efficiency	X	X	X	2
Evaluate thermophilic and mesophilic modes of operation	X	X	X	6
Evaluate effect of particle size on digester performance		X	X	12
Evaluate effect of mixing power and mode on digester performance	X	X	X	7
Evaluate effect of filtrate recycle on digester performance	X	X	X	8
Evaluate effect of solids recycle on digester performance	X	X		20
Evaluate effect of various sewage sludge/solid waste ratios		X	X	18
Dewatering and residual materials disposal				
Evaluate suitability of alternative dewatering equipment over range of potential operating conditions	X	X	X	3
Evaluate cake produced by alternative dewatering equipment for different disposal schemes	X	X	X	4
Evaluate the filtrate produced by alternative dewatering equipment for different disposal schemes	X	X	X	5

during these months is equivalent to 12 percent of the projected curtailment. Over a full 12 months, fuel gas production from solid waste in the major SMSA's could provide almost 30 percent of the projected national curtailment of interstate gas supplies.

Necessity for further work

A proof-of-concept experimental program has been developed to fill in the gaps of knowledge in order to permit a confident design of a full-scale processing facility for the production of fuel gas from solid waste. Table 2 has been prepared as a guide to the relative priorities of various elements of the experimental program. Each experiment has been classified with respect to its significance in proving the technical and economic feasibility of fuel gas production from solid waste and the necessity to conduct the experiment in order to prepare the full-scale facility design.

In January, 1975, the methane production from solid waste program was transfered to the Energy Research and Development Administration (ERDA). ERDA has recently announced that a 45,000—90,000 kg/day (50—100 tpd) experimental facility will be constructed in Pompano Beach, Florida to prove the concept of methane production from urban waste.

CONCLUSIONS

The above projections show that methane produced from municipal waste can have significant impact as a supplemental source of pipeline quality gas. The conclusions come at a time when energy shortfalls and rising costs of refuse disposal are forcing many major communities to reevaluate their refuse disposal practices. Anaerobic digestion of the organic portion of municipal refuse is presently the only known process which will return the energy value of refuse in the form of pipeline-quality gas.

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PRODUCTION OF SINGLE CELL PROTEIN FROM AGRICULTURAL AND FOOD PROCESSING WASTES*

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ABSTRACT

A process has been developed in which carbohydrate wastes are fermented to produce microbial protein suitable for animal feeds. The process consists of (i) a waste preparation step, (ii) growth of a filamentous mould in submerged culture at a low pH (iii) recovery of the mould by filtration (iv) drying and bagging. It is estimated that operating scales as low as five hundred tons/annum can be made economic if the process can be used for most of the year and labour costs are low.

INTRODUCTION

Most crops are grown for only a small part of their bulk, so during harvesting and processing various parts of the plants are discarded. Part is simply ploughed back into the land and makes a valuable contribution to the structure and fertility of the soil. Another part, notably straw and dry leaves, is sometimes burned on the fields because collection and redistribution is too costly. There remains, collected at farms and food processing plants, many hundred of millions of tons per annum of very low value material. Steffgen [1] quoted 400 million tons per annum of solid waste from agricultural and allied industries for the U.S.A. alone. To this must be added many millions of tons of BOD in liquid effluents, so for every ton of food produced a similar quantity of carbohydrate waste is collected and subsequently disposed of, often by burning or oxidation in effluent treatment plants.

The production of microbial protein from wastes of agricultural industries has received attention in recent years with two main objectives in view — upgrading the feed value of solid wastes and removing the BOD from liquid wastes with a bonus in the form of high protein animal feed supplement. These processes face a number of economic and technical problems. The economic problems stem from the distribution of agricultural wastes. They are produced worldwide but in relatively small quantities at individual sites

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and often for only a small part of the year (Table 1). A processing plant built to take advantage of a fruit cull, for instance, would have a throughput of at best a few tens of thousands of tons of fruit, yielding probably less than a thousand tons of single cell protein (SCP). The factory would be inoperative

TABLE 1

Scale and seasonality of waste production

	Papaya	Olive	Palm oil
Average processing plant waste, t/a dry solids	2,000	300	5,000
Season	10/12	4/12	11/12
Estimate of SCP production, t/a	500	100	1,500

for part of the year or would have to operate on a different waste; effluents from e.g. olive processing plants pose similar problems of low throughput and seasonality. These factors make for high amortisation costs, so the technology must be such that the capital cost of plant is minimised for an economically viable operation. Plants that operate year round and on a larger scale, such as those that process corn and palm oil, present less of a problem but still require a simple technology to be commercially viable.

The technical problems of microbial protein production stem from the chemical composition and physical form of the wastes. In general the solid organic material is mostly carbohydrate, at least half of which is cellulose (Table 2). Starches, pectins and sugars form the remainder. If the sugars of

TABLE 2

Composition of agricultural wastes

	Bagasse	Papaya	Palm oil sludge	Potato process water
Total solids, %	49	13	5	0.7
Carbohydrate % of dry solids	82	80	60	75
Fibre	94	9	30	20
Pectins	0	7	NT[a]	NT
Starches	0	NT	NT	60
Oligosaccharides and monosaccharides	4.5	67	NT	NT
Protein	0	5	0.4	8
Lipid	0	5	10	NT
Ash	0.7	6	NT	NT

[a] NT = not tested.

the carbohydrate polymers can be mobilised, they can form the basis of processes such as recovery of sugars or fermentation for ethanol or single cell protein production. In recent years Tate & Lyle, along with other groups [2—6], have developed processes for non-cellulosic carbohydrate mixtures. It has been our intention to use as simple a technology as possible to enable application to small quantities of material, particularly in developing countries. The basis of the processes is the fermentation of the carbohydrate or other organic materials to yield single cell protein (SCP) or in special circumstances ethanol plus SCP.

GENERAL FEATURES OF LOW-TECHNOLOGY SCP FERMENTATIONS

The organisms used for simple recovery of biomass from wastes must have a number of special properties (Table 3) — they must be capable of growth

TABLE 3

Properties of microbes for waste utilisation
Broad substrate specificity
High growth rate
High carbohydrate conversion efficiency
Growth at high temperatures (>35°C)
Growth at extremes of pH
Simple recovery from fermentation
High protein content
Non toxic

on a wide range of carbon sources, preferably simultaneously and they must have a high efficiency of conversion of the substrate to biomass. The last point restricts the choice to aerobic microbes, since in anaerobic growth several times more carbohydrate is consumed to obtain the necessary energy. The organisms that grow on waste in nature may fulfil these criteria and could be used for SCP production. However, they present certain drawbacks — they are usually mixed cultures of a wide range of microbes whose ratios may vary widely with small changes in waste composition or the physical environment. Therefore, the organisms may vary seasonally or be influenced by small upstream process changes, possibly resulting in harvesting problems and considerable variability in the product specification.

An alternative approach is to use a microorganism which has the required characters grown under conditions that favour its growth against that of other microbes. Filamentous moulds have been used because they can be harvested easily by filtration and some species can be grown at low pH and high temperatures that inhibit the growth of contaminating bacteria and yeasts.

A strain of *Aspergillus niger* designated M1 has been isolated from naturally rotting material and found to conform to most of the criteria listed above [3,4]. More recently, a *Fusarium* sp. studied in our laboratories has been found to have an unusually high protein content. Both species grow on a wide range of carbohydrate-containing substrates (Table 4). Glucose, the most common constituent of carbohydrates, is rapidly assimilated by most microbes. The glucose dimer maltose and the polymer amylose were almost as

TABLE 4

Growth of *Aspergillus niger* (M1) and *Fusarium* sp. (M4) on single carbon sources

The carbon source was added at 2 g/l to an inorganic salts agar medium in petri-dishes. The plates were inoculated with a small amount of mycelium and conidia. +, growth; –, no growth

Substrate	M1	M4
Glucose	+	+
Maltose	+	+
Lactose	+	+
Cellulose (Whatman Cellulose powder CC41)	–	–
Rhamnose	+	+
Cellobiose	+	+
Xylose	+	+
Glycerol	+	+
Pullulan	+	+
Galacturonic acid	+	+
Soya oil	–	±
Pectin (apple)	+	+
Glutamic acid	+	+
Casein	+	+
Acetic acid	–	–
None	–	–

readily utilized by both the *Aspergillus* and the *Fusarium*. Growth on pullulan indicates the ability to cleave the $\alpha(1\text{—}6)$ glycosidic links that form the branch points in starches. Pectin is a polygalacturonic acid present in many fruits and pectinolytic activity was found in both strains. However, neither were able to use cellulose as the carbon source. Amino acids, proteins and lipids which are present in small amounts in most biological waste materials were used by the *Fusarium*. Clearly these mould strains, whose natural habitat is rotting fruit, etc., have a very broad substrate specificity. In nature substrates are normally found in complex mixtures which may also contain compounds inhibitory to microbial growth. Growth tests using a wide range of waste materials showed that in most cases the moulds grow well (Table 5).

Having established that the moulds were capable of growth on a wide range of substrates, fermentation conditions were devised under which high yields of protein could be obtained. The carbohydrate conversion efficiencies and the growth rates were measured in 5 l batch cultures in aseptic laboratory

TABLE 5

Growth of two moulds on agricultural wastes[a]

Scoring refers to a combination of colony radial growth rate and density on agar plates

Substrate	*A. niger* (M1)	*Fusarium* sp. (M4)
Carob extract	++	++
Sulphite waste liquor	+	NT
Molasses	++	++
Olive blackwater	++	++
Cassava flour	NT	++
Papaya slurry	++	++
Citrus waste	+	+

++ good growth; + poor growth; – no growth; NT not tested.

fermenters. Oxygen was supplied in excess as measured by in situ membrane electrode, i.e. the oxygen concentration was greater than 2×10^4 Pa. The pH was controlled to ± 0.2 unit by automatic addition of sodium hydroxide or hydrochloric acid. Temperature was controlled to within 0.5°C of the set value. The basal salts medium contained (g/l), $(NH_4)_2SO_4$, 7.0; NaH_2PO_4, 2.0; $MgSO_4 \cdot 7H_2O$, 0.3; $CaCl_2 \cdot 6H_2O$, 0.3; KCl, 0.1; Zn Cl_2, 0.2; $FeSO_4 \cdot 7H_2O$, 0.005; Difco yeast extract, 2.5.

The pH had little effect on the conversion efficiency or growth rate over the range 3.0—6.0 (Fig.1). Below pH 4.0, the growth rate fell but the conversion efficiency was almost unchanged. The ability to grow at pH 2—3 is a valuable feature, since most saprophytic bacteria and yeasts grow poorly or not at all at acid pH. Repeated open cultures in the pH range 2—4 have not shown gross contamination by extraneous microorganisms. Aseptic precautions, which are expensive on a production scale, are therefore unnecessary.

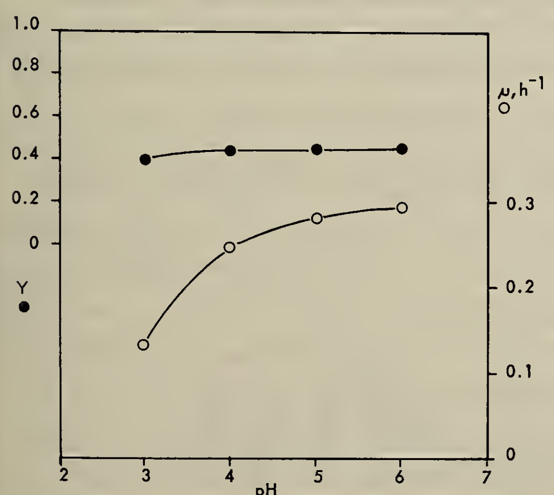

Fig. 1. Carbohydrate conversion efficiency (*Y*) and specific growth rate (*μ*) of *Fusarium* sp. (M4) in batch cultures: effect of pH. Carbohydrate: sucrose, 40 g/l; temperature 30°C.

The optimum growth temperature for *Fusarium* sp. (M4) was 35°C (Fig. 2), growth almost stopping at 40°C at pH 4. At lower pH the growth rate was higher at 40°C but stopped at 42°C. The ability to grow over a wide range of temperatures is important since heating and cooling facilities must be avoided to minimise the cost of fermentation. The conversion efficiencies found here are close to the maximum growth efficiencies reported for filamentous moulds [7,8].

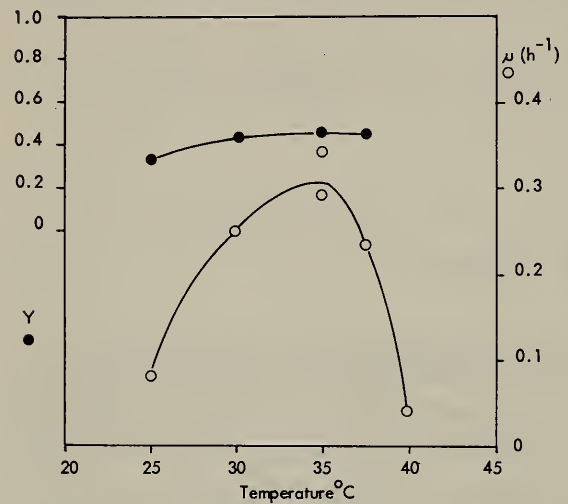

Fig. 2. Carbohydrate conversion efficiency (Y) and specific growth rate (μ) of *Fusarium* sp. (M4) in batch cultures: effect of temperature. Carbohydrate: sucrose, 40 g/l; pH 4.0.

The effects of pH and temperature on growth rates and carbohydrate conversion efficiencies were established in the presence of excess oxygen. The oxygen demand of rapidly growing cultures of a mould at 10—20 g/l dry weight is in the range 100—200 mmoles/l/h. To satisfy this demand requires the use of high-powered aeration and mixing systems. But to install such systems would be inefficient since the peak oxygen demand occurs for only a few hours in a batch fermentation cycle of 20 h. Lower power inputs which would cause oxygen-limitation of growth would extend the fermentation cycle but would consume less power overall. However, during oxygen-limited growth, many organisms exhibit mechanisms for gaining energy which give a low conversion efficiency of carbohydrate to biomass and leave a residue of organic material in the process water. When the *Fusarium* sp. (M4) was grown under oxygen-limited growth conditions the growth rate was lower, but the oxygen respired and carbohydrate efficiency was unchanged and extracellular organic compounds did not accumulate (Table 6). Thus, oxygen-limited growth conditions may be used to control the rate of growth and to save power costs.

The product of this fermentation is a mass of fine filaments, or hyphae, which make up the fungal mycelium. The crude protein content of the dry mycelium was in the range 25—35 percent for *A. niger* (M1) and 41—51 percent for *Fusarium* sp. (M4). The actual protein content calculated from the amino acid composition was 70 percent of the crude protein for *A. niger* (M1) and from 80 to 90 percent of the crude protein for *Fusarium* sp. (M4). The

TABLE 6

Effect of oxygen-limitation of growth on carbohydrate conversion efficiency of *Fusarium* sp. (M4)

Inoculum, 2 g biomass/l; pH 4.0; temperature 35°C; 40 g/l sucrose.

	Oxygen excess	Oxygen-limited
Maximum O_2 transfer rate, mole/l/h	0.100	0.025
Oxygen consumed, moles/l	0.56	0.53
Biomass produced, g/l	17	16.3
Carbohydrate yield constant	0.43	0.41
Time to reach max. biomass, h.	12	20

amino acid profiles (Figs. 3 and 4) are similar to soya meal. Feeding trials with chickens and pigs have shown the material for strain M1 to be non-toxic. It was a good substitute for part or all of the soya bean meal in feeds for pigs. The results of chick growth trials varied with the waste used for the preparation of the SCP and further tests are to progress to elaborate upon the results.

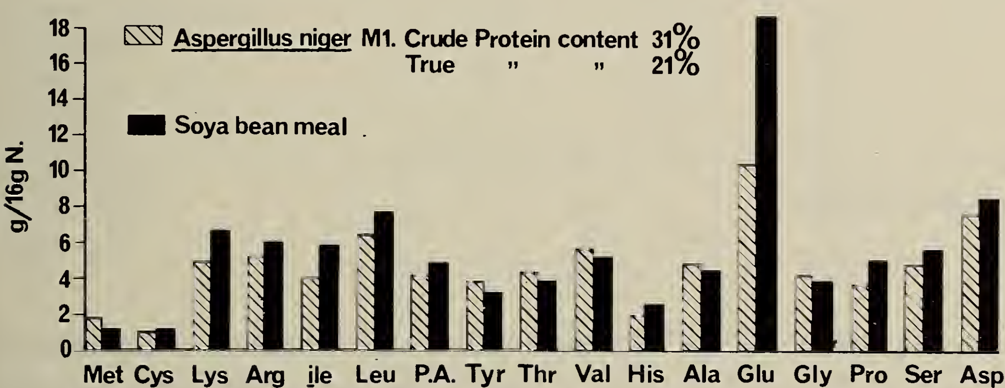

Fig. 3. Amino acid content of mycelium.

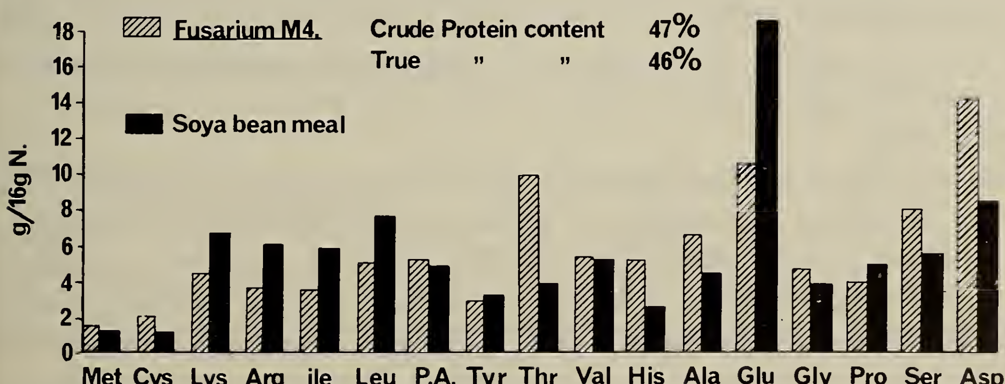

Fig. 4. Amino acid content of mycelium.

PROCESS DESCRIPTION

Waste materials suitable for the growth of the microbes described above can be classified broadly into two categories. These are the solid or semi-solid wastes such as spoiled fruit, carob pods, date waste and molasses, and low concentration wastes which are usually pollution hazards, such as olive and palm oil process water, corn steep water and canning wastewater. Carob pods and spoiled papaya have been studied in our laboratories (Table 7). The carob tree is found in the Mediterranean countries. Its bean is collected for a valuable gum. The pod has a high sucrose content and has long been used in cottage industries for making syrup and sweets. The papaya is a soft-fleshed tropical fruit which has a substantial local consumption and is also packed for expensive markets in the U.S.A. and Carribean.

TABLE 7

Analysis of carob and papaya waste

Waste	Carob pod	Papaya cull
% dry matter	70	13
Composition % of dry matter		
Fibre	5.8	9
Sugars	54.9	67
Pectin	—	7
Protein	4.5	5
Lipid	0.5	—
Ash	3.0	6
kg dry SCP production per ton fresh waste	250	60

A waste such as papaya cullage may be slurried with water or in the case of the carob pod a hot water extract may be made. The concentration is adjusted to give approximately 4 percent fermentable carbohydrate and the medium is fermented to give approximately 2 percent fungal biomass. Slurrying and fermenting the entire waste results in an increase in protein content of dry material of from 15 to 25 percent. If an extract of fermentable carbohydrates is made, the dry product contains from 30 to 50 percent protein, depending upon the fungus used.

The simplest apparatus for treatment of solid wastes consists of a tank in which the slurry or extract is prepared, a fermenter equipped with a stirrer and an air compressor, and a rotary vacuum filter. The total power consumption is about 1.0 kwh/kg biomass at 25 percent solids. A plant of this type will be installed in Belize in the near future. It will produce about 100 ton/year of single cell protein from a variety of waste materials. For plants much larger than 100 ton/year, a cooling system is required to remove the heat of fermentation. If possible, the wet cake should be fed, after pasteurisation, directly to animals, thereby avoiding the expensive drying step. If dried, the material can be bagged and is stable for months.

Microbiologically, the process is a simple batch fermentation. The waste is prepared and a small quantity of diammonium phosphate, or other ammonium salt, is added to give sufficient anions to produce a low pH as the ammonium ion is assimilated. The fermenter is inoculated with a large number of spores of the mould which germinate and grow as long branched filaments. During growth the pH falls rapidly and the growth of contaminant microbes is inhibited. After about 20 h the fermentable carbohydrate is exhausted and growth stops. About 90 percent of the culture is harvested by filtration and the remaining 10 percent is left as inoculum for the next batch of medium.

The capital cost of equipment is low, $56,000 for the smallest plant envisaged, 100 ton/year (Table 8). However, the operating costs per ton of product are high on such a small scale (Table 9). In this example, the cost of

TABLE 8

Microbial protein production from solid agricultural waste — Capital costs

SCP production (300 day operation)	100 ton/year $ 000	500 ton/year $ 000
Material preparation	7	12
Fermenter	5	14
Aeration	6	16
Cooling	—	6
Filtration	11	41
Water filters	3	9
Installation	9	23
Buildings	5	14
Dryer	10	30
Total	56	165

TABLE 9

Microbial protein production from solid agricultural waste — Operating costs

SCP production (300 day operation)	100 ton/year $ 000	500 ton/year $ 000
Raw materials	2.7	13
Power (150 MWh/700 MWh)	3.0	15
Labour	20.0	30
Direct cost	25.7	58
Amortisation (10 year)	5.6	16.5
Finance (10% interest)	5.6	16.5
Total	36.9	93
Unit cost	$ 369/ton	$ 188/ton

skilled labour in Belize, and an arbitrarily chosen 10 year amortisation period were used. The process could be economic on the 100 ton/year scale only in countries with cheap labour since labour contributes over half of the cost. As the scale of operation is increased, the unit price decreases.

The treatment of watery effluents from agricultural processing plants differs in several respects from that of solid wastes. Effluents are often produced 24 hours per day and for much of the year. The concentration of substrates for fermentation is low — no more than 25 g/l for palm oil process water and more normally less than 5 g/l for wastes from the canning industry and from starch processing (Table 10). In these cases, the reduction of the

TABLE 10

Analysis of potato and palm oil process effluents

	Potato process water[a]	Palm oil process water
Solids, %	0.7	5.0
Carbohydrate, % dry solids	80	60
Fibre	20	30
Pectin	+	+
Reducing sugars	+	+
Starches	60	N.T.
Protein	8	0.4
Lipid	+	10
Ash	<10	ca. 5
BOD_5, mg/l	400	22000
Volume of effluent	80 m^3/h	20 m^3/h
Potential SCP production	180 ton/year	ca. 3000 ton/year

[a] + present as minor component; NT not tested.

biological oxygen demand (BOD) may be more important than the production of SCP. At least three fungal processes are already in operation for simultaneous BOD reduction and SCP production. The "Symba" process using an *Endomycopsis* to hydrolyse starch in wastes followed by yeast growth on the sugar was developed in Sweden many years ago [6]. The Pekilo process for starch wastes and sulphite waste liquor uses conventional aseptic continuous culture in stirred fermenters [5]. The lagooning process described by Church et al. [2] for corn processing wastes is reported to have turned effluent treatment into a profitable operation. Work in our own laboratories, and in conjunction with Dr. R.N. Greenshields at Aston University, has centred on the use of unstirred tower fermenters [9]. The process water, after addition of inorganic salts, is percolated up a column-shaped fermenter. Aeration is accomplished by sparging air through a perforated base plate. The mould grows in this column and is retained in the fermenter by means of a stagnant zone at the top which causes the mycelium to settle back into the fermenter whilst the water flows off. Thus, high concentrations of mould are held in the fermenter to permit rapid processing of the waste in relatively low fermenter capacities. The form of the mycelium is important in such fermenters; it must be as tightly-branched tiny pellets, giving a macroscopic appearance of sandgrains, to enable efficient aeration and sedimentation. In other aspects the process is similar to that for solid wastes. Costings made on the basis of a very high BOD material — palm oil waste from a typical factory — show the process to have a capital cost of less than $250,000 for a plant processing over 500 m^3/day (Table 11). The process appears to be profitable using U.K. labour costs when the product is sold at the U.K. soya meal price (Table 12).

TABLE 11

Microbial protein production from process effluents — Capital cost

	$ 000
Fermenters, 4 × 10 m^3	55
Air compressor, 20 m^3/min	18
Filtration	46
Dryer and bagger	60
Installation	30
Buildings	25
Total	234

Land area required approx. 280 m^2; Effluent: 20 m^3/h; 22000 mg/l BOD_5; 300 day/year; 1500 ton/year SCP.

TABLE 12

Microbial protein production from process effluents — Operating cost

	$ 000
Raw materials per annum	40
Power (1200 MWh)	24
Labour	125
Direct cost	189
Amortisation (10 years)	23
Finance (10% interest)	23
Total	235
BOD cost	7.4 ct/kg
SCP cost	16.0 ct/kg
SCP sale at U.K. soya price	20.0 ct/kg
Net profit	2.0 ct/kg BOD

MASS AND ENERGY BALANCE

It can be argued that in a world with limited material resources, in particular energy, processes should be subjected to analyses of conservation mass and energy as well as conventional costing procedures. The process can then be compared with others which use the same raw material or produce the same product and an assessment made of its relative efficiency. The practical value of such analyses depends upon a knowledge of the factor limiting agricultural productivity, e.g., supply of energy or provision of protein or of calorific food intake. This value in turn depends on the social and political priorities set by the community. Here we have made a restricted analysis of the mass and energy balances for SCP production from wastes without the knowledge of what limits overall agricultural productivity.

The substrate mass balances for SCP production (Table 13), show that

TABLE 13

Carbon and nitrogen balance

Carbohydrate 1 kg carbon	+	Oxygen 1.3 kg	⟶	SCP 0.5 kg carbon	+	CO_2 1.8 kg	+	3.1 MJ
$(NH_4)_2HPO_4$ 1 kg N			⟶	SCP 0.9 kg N	+	Effluent 0.1 kg N		

most of the nitrogen is retained in the product, but half of the carbohydrate is lost, used for energy for the synthesis of the highly ordered biological macromolecules. However, if the materials would otherwise be burnt, buried or discharged to the rivers and seas, the recovery of 50 percent of the carbon represents a net increase in carbon available to the food system, gained at the expense of a small quantity of fixed nitrogen. Similarly, a summation of the energy inputs to the process can be made and compared with the energy content of the SCP recovered. The power consumption of the plant plus the energy content of the ammonium salt is the input, equivalent to *c* 3.5 MJ/kg dry SCP. The energy recovered as SCP is *c* 6.4 MJ/kg [10]. Thus, ignoring the energy tied up as plant and the energy used as manual labour, there is a net gain of 2.9 MJ/kg.

CONCLUSION

The partial recovery of agricultural wastes as single cell protein could make a contribution to conservation of the fixed carbon resources produced on the land. In certain circumstances, wastes can be recovered by commercially viable processes, particularly where an expensive alternative disposal method is necessary. Even operating scales as low as a few hundred tons/year can be made economic if the process can be used for most of the year and labour costs are low, conditions which can be met in many developing countries.

ACKNOWLEDGEMENTS

Our thanks are due to Dr. G.G. Morris and Mr. S.A. Campbell who did much of the laboratory work on which the processes are based.

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PROBLEMS AND POTENTIAL ASSOCIATED WITH THE PRODUCTION OF PROTEIN FROM CELLULOSIC WASTES*

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ABSTRACT

Annually, billions of tons of cellulose are included in agricultural and municipal waste streams. This cellulose could be the feedstock for biological and chemical conversion to useful and valuable products. Bioconversion could add to the world's protein supplies as well as supply a variety of chemicals. There still remain technical constraints hindering development of viable bioconversion processes utilizing these wastes. The cellulose is resistant to rapid assimilation by microorganisms because of its semicrystalline nature. One way to overcome this resistance is to pre-treat the cellulose photochemically, followed by a novel acid hydrolysis. Such processing yields a cellulose to glucose conversion of from 40 to 50 percent per pass through the reactor.

INTRODUCTION

The prevalence of poverty and pressure of population growth in various parts of the world, especially in less developed areas, have made it difficult to provide many peoples with an adequate nutritional diet, particularly with respect to protein content. This problem, which may become even more serious in time, is due, in part, to an inefficient world food distribution system, a world shortage of fertilizers and energy, and climatological conditions that have produced droughts and flooding in many parts of the world. Development of technology for the conversion of renewable organic materials (i.e., agricultural crop residues and the organic fraction from municipal and industrial waste streams) could potentially have a profound impact on both fuel and protein shortages throughout the world.

Historically, as early as 1883, Hoppe-Seyler recognized the decomposition of organic matter under natural conditions [1]. Omelionski [2] pioneered much of the early work on the fermentation of cellulose by microorganisms to form gases, fluids, and humus. Many papers and patents have been published

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on the possibility of producing organic acids, alcohols, and methane through fermentations of cellulose by microorganisms. Unfortunately, progress over the last 100 years on the utilization of cellulose as a feedstock has not been impressive nor has the use of organic waste fulfilled its potential as an inexpensive feedstock to produce food and energy products through fermentation technology.

BIOCONVERSION PROCESSES

Although bioconversion processes have been extensively researched with some success as a mechanism for utilizing organic waste, there appears to be a growing, new interest in the process prompted by:

— the recent 300 percent increase in crude oil prices which improves the competitiveness of processes considered marginal in the past,

— increased freakish weather patterns causing droughts in some parts of the world and floods in others, resulting in unpredictable annual crop yields,

— costs of food, fertilizer, and fuel that have sharply increased in price, and

— world food reserves that have now dropped to less than a 30-day supply, with the United States and Canada no longer having substantial reserve food stock to respond to world emergencies.

The sources of organic wastes for use in bioconversion processes include agricultural crop residues, waste paper from domestic refuse, sewage, animal wastes, paper mill sulfite liquor, and food processing waste.

Technical constraints that hinder development of viable bioconversion processes

Cellulose is the major constituent of organic feedstocks. It occurs in the presence of hemicellulose, a related structure, and with lignin, a nonpolysaccharide.

The cellulose molecule is a polymer with molecular weight generally in the range of 600,000 to 1,500,000. Its degree of polymerization (DP) ranges from approximately 3,000 to 10,000. Glucose, as well as cellobiose, cellotriose, and cellotetrose, can be isolated when cellulose is hydrolyzed. Complete hydrolysis by acid yields D-(+)-glucose as the only monosaccharide. Other polysaccharides can also occur in the presence of cellulose. For example, cereal straws and bran contain pentosans (most commonly xylan, which is built up from *d*-xylose units), which yield pentoses on hydrolysis, rather than glucose. Starch is present in the majority of plants, and this material is synthesized from glucose units.

Cellulose in organic materials occurs in two forms — the amorphous, which is susceptible to enzyme and acid hydrolysis, and a much less susceptible crystalline form. In crystalline or native form, the cellulose molecules are stabilized laterally by hydrogen bonding between hydroxyl groups of adjacent molecules. Hydrogen bonding and the arrangement of the cellulose molecules in native cellulose has been described by Liang and Marchessault [3]. An excellent discussion and bibliography of review articles on this subject is provided by Ward [4]. He points out that the consequence of the high degree of order in native cellulose is that not even water molecules, let alone enzymes, can enter the structure. Consequently, native cellulose is essentially inert in the biological and chemical processes.

Pretreatment processes

Before agricultural crop residues and other cellulosic solid wastes can efficiently and economically be used as substrates for bioconversion processes to produce energy and microbial protein, an inexpensive way must be found to modify this material so that it can be consumed easily and quickly. A number of physical and chemical processes with the potential for enhancing fungal digestion of waste cellulose have been evaluated and reported on in an earlier publication [5]. The treatment processes evaluated included alkali, electron irradiation, microwave, laser, viscose, and photodegradation. Although significant structural changes occurred in pretreated cellulosics, these changes were not translated into dramatic improvements in the conversion rates of waste to desired products. One of the cellulose pretreatment techniques that appeared promising, inexpensive, and practical for conditioning large quantities of waste was sensitized photodegradation.

Rader and Schwartz [6] revealed that polysaccharides such as starch and cellulosic materials, in the presence of a water-soluble metal or nitrogen-base salt of nitrous or hyponitic acid, are converted to saccharides of lower molecular weight by irradiation with light that is rich in frequencies in the neighborhood of 355 nm. On the basis of this information, Fookson and Frohnsdorff [7] conducted a study to evaluate the technical and economic feasibility of using the sensitized photodegradation process to increase the use of waste cellulose in bioconversion processes.

Cellulose (Eaton-Dikeman cotton linter papers) was irradiated in a reactor at varying wave lengths and intensities. The optimum $NaNO_2$ concentration required to decrease the degree of polymerization (DP) was determined. The cotton linter papers were subjected to 0, 0.1, 1.0 and 10 percent $NaNO_2$ additions. The results of this experiment (Fig. 1) suggest, for the 253.7 nm lamps and within the range of conditions used, that 1 percent by weight $NaNO_2$ could reduce the DP of cellulose containing materials.

Test for fungal growth response

The samples of cellulose treated with $NaNO_2$ and irradiated to reduce the DP were tested for their ability to be utilized by fungi. With reduced DP, in addition to no significant increase in carboxyl or carbonyl groups, the rate of cellulose degradation should have increased significantly.

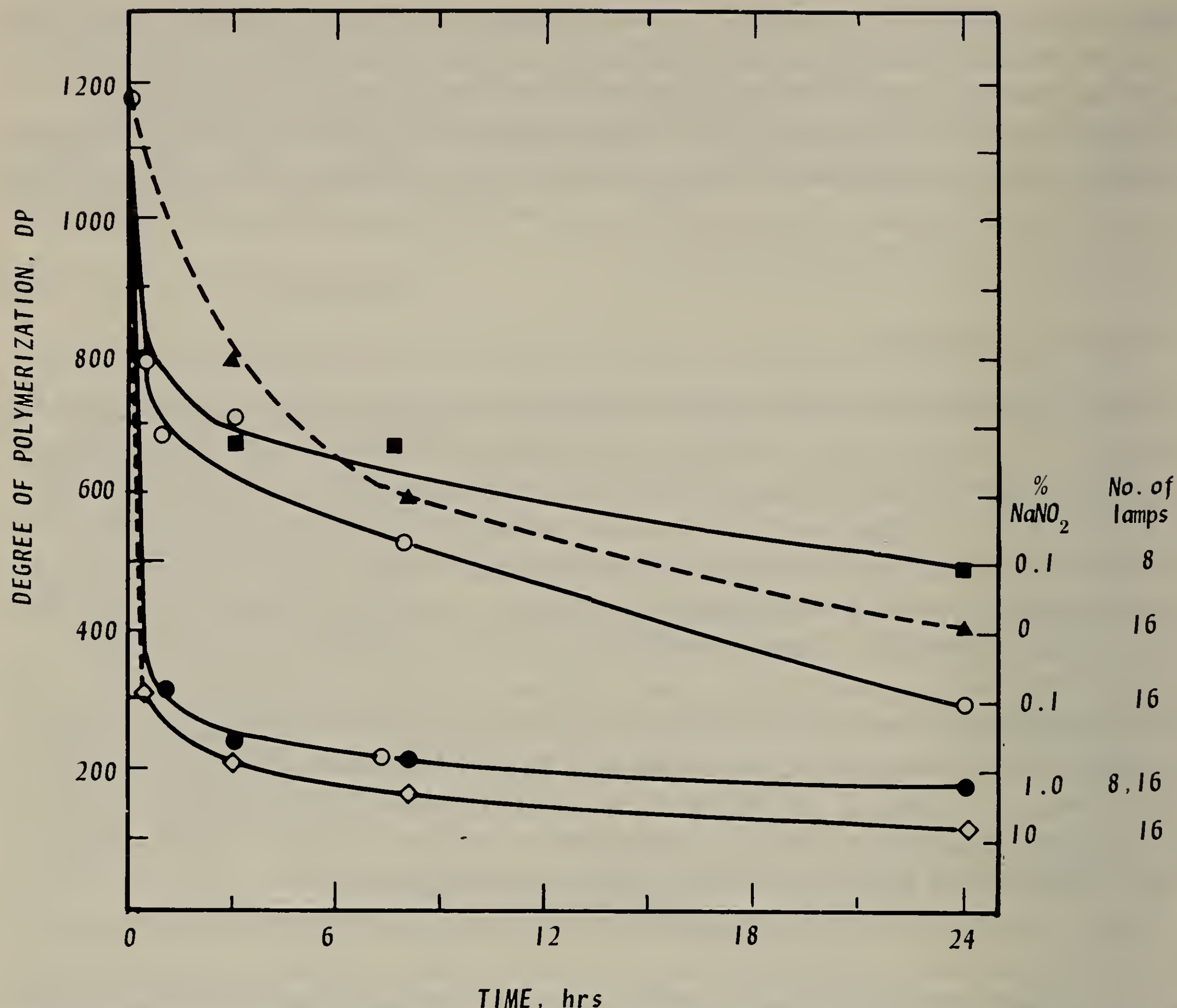

Fig. 1. Effect of 253.7 nm radiation on $NaNo_2$-treated Eaton-Dikeman cotton linters paper.

One gram of each cellulose sample was placed in 100 ml of a mineral salts medium and inoculated with a selected fungus as described by Rogers and Coleman [5]. The reduction of the DP did not improve the digestion rate of cellulose as expected. Future plans, however, call for studies to determine if photodegradation can be implemented to improve the yield of glucose by subsequent high temperature/high pressure acid hydrolysis.

Unlike conventional acid hydrolysis processes, a novel process will be investigated that brings an acid-treated waste cellulose at ambient temperatures almost instantaneously to the optimal hydrolysis reaction temperature by contact with superheated water or steam. Preliminary data suggest that a combination of photochemical treatment and this method of acid hydrolysis could give a cellulose—glucose conversion of from 40 to 50 percent per pass through the reactor [8].

PROTEIN PRODUCTION PROCESS

The basic processing scheme for producing protein from organic waste is outlined in Fig. 2. After separation from the inorganic materials, the organic waste is ground and physically or chemically pretreated. For direct use of cellulose, the pretreatment may involve the use of a swelling agent or hydrolysis to glucose. The feedstock is passed into the fermenter, which contains the growth nutrients dissolved (containing K, N, P trace elements) in water. The microbes utilize the carbohydrates and nutrients to produce a biomass which is recovered as protein (single-cell protein).

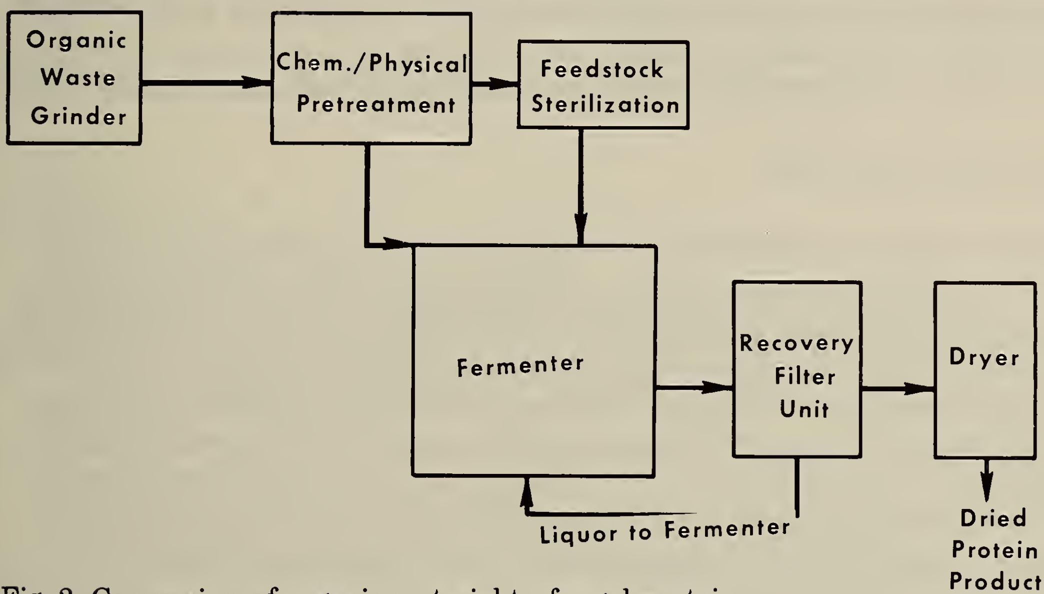

Fig. 2. Conversion of organic material to fungal protein.

Fermentation technology has been advanced to maximize microbial protein production to the point that a highly instrumented fermenter can be coupled to a digital computer for control [9]. Using this device, a "dose response" technique can be used to determine the optimum carbon to nitrogen ratio. For example, yeast cells (7.5 g/l) were grown to a density of 105 g/l (dry weight) in 14 hrs fermentation at a growth rate of 7.5 g/l/hr. This is reported to be the highest yield ever reported for the yeast *Candida utilis*. The industrial average is approximately 25 g/l dry weight [9]. Protein yields can further be increased up to 15 percent by adding compounds such as indole-3-acetic acid or 2,4-dichlorophenoxyacetic acid in concentrations of parts per million to the growth media [10].

The production of microbial protein from organic wastes has already been demonstrated on a small scale; what is lacking is information on the economic feasibility and future markets for the protein product produced in this country.

Potential advantages of using microbial production processes

A number of factors weigh heavily in favor of developing microbial protein production processes to augment conventional protein deficits. Microbial protein offers the following possible advantages over conventional processes:

— Greater feedstock conversion to protein (for cattle, 3.6 kg grain yields 0.453 kg beef on a feed lot; for single cell protein (SCP), 3.6 kg feed yields 1.45 kg/SCP, dry weight.
— Prevents loss of nutrients such as N, P, K compared to the uncontrollable loss with conventional farming methods.
— Is not influenced by freakish weather patterns (i.e., flooding, frost, droughts, etc.).
— Is produced from renewable resources without interfering with primary productivity of agricultural land.
— Is less energy intensive than some conventional farming methods [11,12].

USE OF MICROBIAL PROTEIN

Tortula yeast grown on molasses or sulphite liquor has long been used in food in small quantities, primarily as a vitamin source. There is a limitation on the amount of microbial protein that can be used directly in human diets since rapidly growing cells have a high nucleic acid content which man would convert to uric acid. Too much uric acid may lead to its deposition in joints where it causes gout, or in the kidneys where it may lead to stone formation. As an alternative to direct human use of fungal protein, a short-term preliminary trial of feeding fungal protein to rainbow trout was conducted at Oregon State University Food Science and Technology Laboratory [13]. The fungal protein was 25 percent of the total diet and fed to young rainbow trout over a 2 month period. This fungal protein was substituted for fish meal and the trout grew as well on this diet as they did on the control feed. The feeding enthusiasm was excellent and the animals exhibited no signs of toxicity. Presently, more extensive fungal protein feeding studies with chicks are being conducted at Tennessee State University.

MARKETS AND FUTURE MARKETS VALUE OF SINGLE CELL PROTEIN

Many chemical specialists believe that single cell protein will become a world commodity [12]. First, it is apt to be included in small tonnages in specialty markets, such as milk powder replacements. Within 10 years, the larger commodity class tonnage is likely, if a number of variables in world protein production — such as soybean price level, weather, international agricultural and monetary policies and sociological and psychological reactions to eating microbial protein — permit. The potential market value of various sources of single cell protein has been given [12].

CONCLUSIONS

The general consensus is that the malnutrition crisis in the world today is largely a protein shortage [14,15]. Current research and development efforts to obtain protein by growing microorganisms on hydrocarbon and waste organics should be intensified to help provide protein to millions of people suffering from starvation.

Because of the chemical and physical properties of cellulosic materials that slow its microbial conversion to protein, new conceptual approaches should be researched and developed to improve rates of conclusion and product yields. Utilizing organic waste in biological systems is greatly simplified if the feedstocks are transformed to a more enzymatic active form or are hydrolyzed to glucose. Until pretreatment technology for cellulose is developed to increase rates and yields, the prospects of using organic wastes as feedstock in economically viable fermentation processes are not optimistic.

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ENZYMATIC HYDROLYSIS OF CELLULOSIC WASTES TO GLUCOSE*

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ABSTRACT

Conversion of cellulose to glucose for the production of food, fuel, and chemicals can be accomplished by acid hydrolysis or by enzymatic processes. Enzyme complexes derived from the fungus *Trichoderma viride* have been found effective in the conversion of cellulosic wastes into glucose syrups. *Trichoderma viride*, a fungus found in nature, is the only fungus known that produces a specific enzyme which is capable of reacting with the crystalline fraction of the cellulose molecule.

This paper discusses the production and mode of action of the cellulase complex produced during the growth of *Trichoderma viride*, and the application of such enzymes for the conversion of various municipal, agricultural and industrial cellulosic wastes to glucose sugar. Included in the discussion are process variables, such as substrate pretreatment, slurry concentration and enzyme activity, as they affect process conversion rates.

Cellulose is the most abundant organic material which can be used as a source of food, fuel and chemicals. The net world-wide production of cellulose is estimated at 90,718 Tg (one hundred billion tons) per year. This is approximately 68.04 kg (150 lbs.) of cellulose per day for each and every one of the earth's 3.9 billion people. The energy to produce this vast quantity of cellulose comes from the sun and is fixed by photosynthesis.

Since cellulose is the only organic material that is annually replenishable in very large quantities, ways must be explored to utilize it as a source of energy, food, or chemicals (Fig. 1). Cellulose can be converted to glucose by either acid hydrolysis or enzymatic processes [1,2]. The use of enzymes is more advantageous. When using acid, expensive corrosion-proof equipment is required. Moreover, the crystalline structure of cellulose makes it resistant to acid, therefore the temperature and acid concentrations needed to achieve hydrolysis also cause decomposition of the resulting sugars. Consequently, the process must be balanced so that the rate of hydrolysis is high enough to compensate for decomposition of the desired products. Glucose yields of approximately 50 percent of the weight of cellulose used have been obtained [3]. Waste cellulose invariably contains impurities which will react with the acid, thereby producing other unwanted by-products and reversion compounds.

On the other hand, the Natick Development Center has developed an enzymatic process which is specific for cellulose and does not involve reactions

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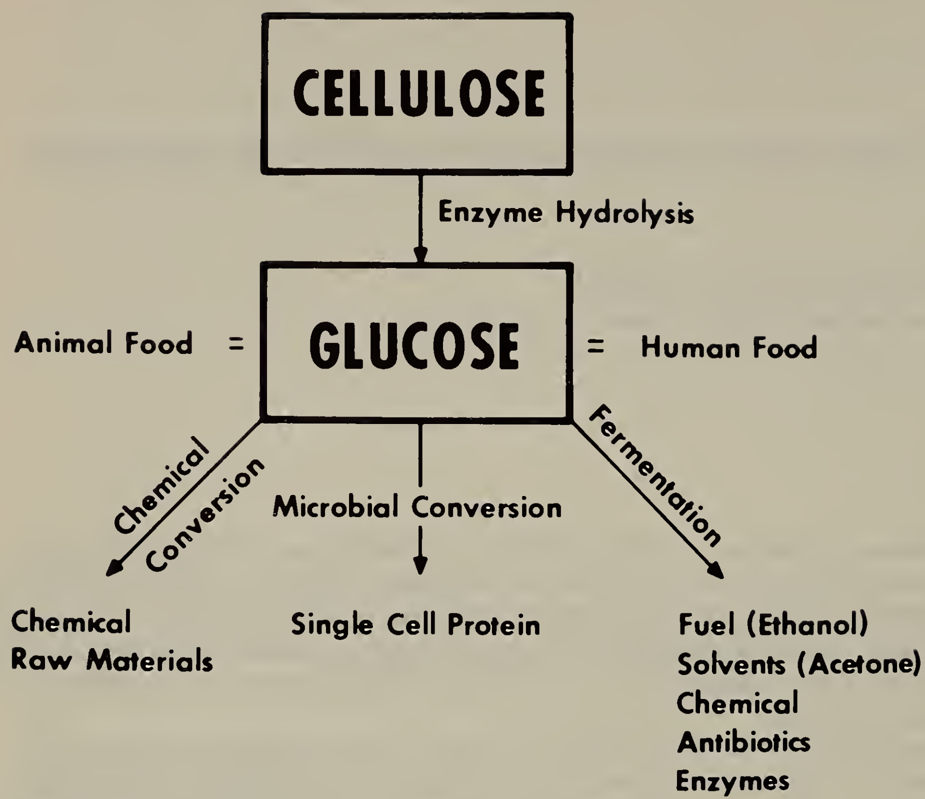

Fig. 1. Cellulose — A chemical and energy resource.

with impurities that may be present in the waste. Moreover, reactions take place under moderate conditions so that the glucose yield is 111 percent of the weight of cellulose used. The glucose syrups produced enzymatically are fairly pure and constant in composition. This enzymatic process is based on the use of the cellulase derived from mutant strains of the fungus *Trichoderma viride.* A schematic diagram of this process is shown in Fig. 2. The first step is the production of the enzyme. This is accomplished by growing the fungus *Trichoderma viride* in a culture medium containing shredded cellulose and various nutrient salts. Following its growth, the fungus culture is filtered and the solids discarded. The clear straw colored filtrate is the enzyme solution that is used in the saccharification reactor. Priot to its introduction into the reactor, the enzyme broth is assayed for cellulase activity and its acidity is adjusted to a pH of 4.8. Milled cellulose is then introduced into the enzyme solution and allowed to react with the cellulase to produce glucose sugar. Note that saccharification takes place at atmospheric pressure and at a temperature of 50°C. The unreacted cellulose and enzyme is recycled back into the reactor, and the crude glucose syrup is filtered for use in chemical or microbial fermentation processes to produce chemical feedstocks, single-cell proteins, fuels, solvents, etc.

The key to this process is production of a high quality cellulase enzyme complex from *Trichoderma viride* capable of hydrolyzing insoluble crystalline cellulose. This enzyme complex consists of two major components, C_1 and C_x. The C_x component consists of exo- and endo-β-1,4-glucanases. These enzymes

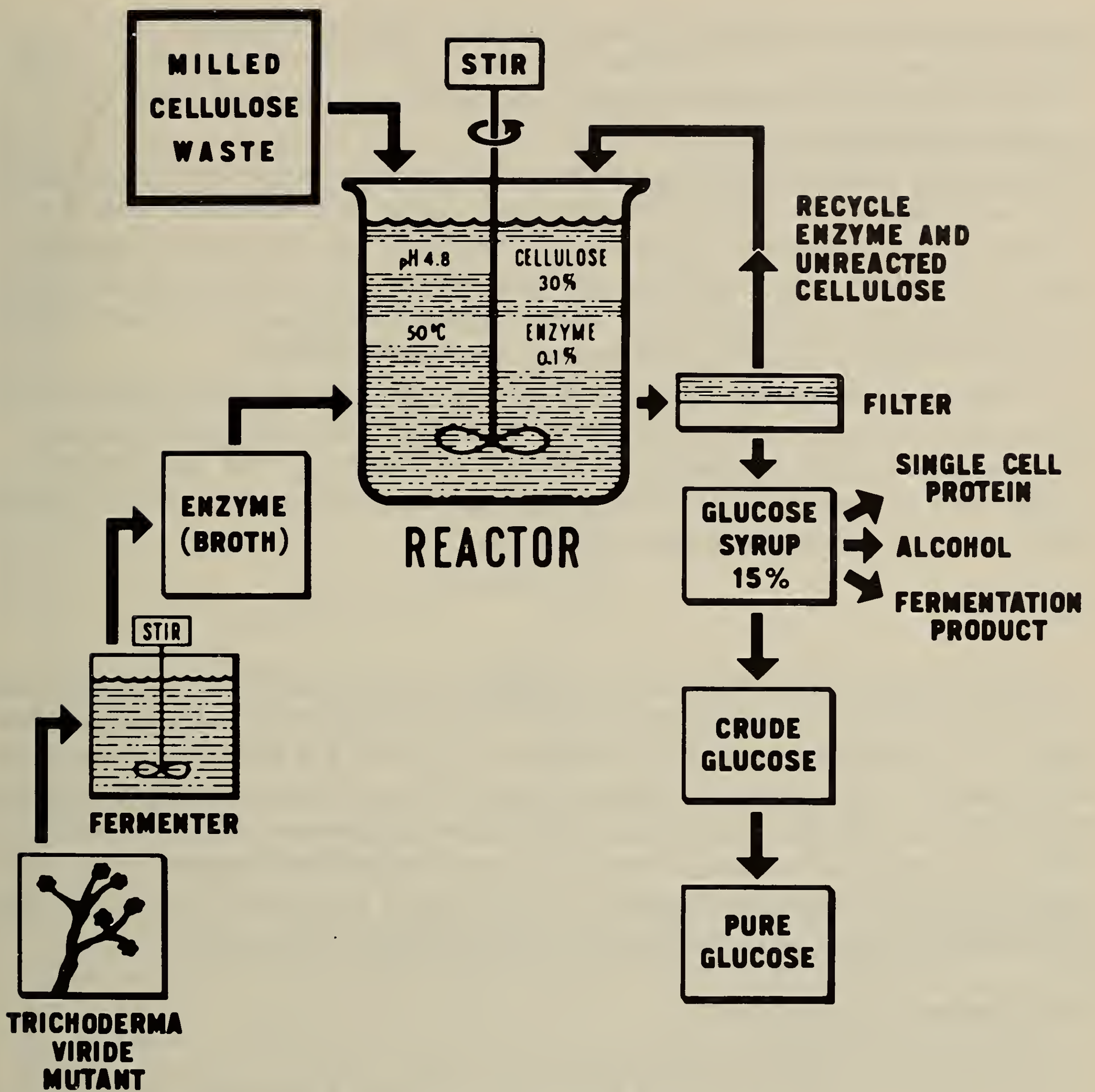

Fig. 2. Enzymatic conversion of waste cellulose to glucose sugar.

are very common and they rapidly attack amorphous cellulose or soluble derivatives such as carboxymethyl cellulose (CMC) producing glucose and cellobiose.

The C_1 is an enzyme required along with C_x for the hydrolysis of insoluble and particularly crystalline cellulose. The action of C_1 is not yet clear although it has been separated from C_x and it is a protein [4]. The simplest explanation, and the one held by E.T. Reese, is that it is a prehydrolytic enzyme, i.e., it decrystallizes or hydrates cellulose chains so the C_x can catalyze their hydrolysis to glucose [5].

C_x enzymes are fairly common but C_1 enzymes are quite rare. The best source known is *Trichoderma viride* [4]. When considering large-scale hydrolysis of cellulose, C_1 is the limiting factor, consequently, it is essential to use cellulases containing both C_1 and C_x for effective saccharification. Most commercial cellulases are obtained from *Aspergillus niger* and contain chiefly C_x with only traces of C_1. The cellulase produced by *Trichoderma viride* is rich in C_1 and endo-β-1,4-glucanase. It also contains lower levels of exo-β-1,4-glucanase and β-glucosidase.

For twenty years, extensive studies of *Trichoderma viride* and its enzyme have been made at the Natick Development Center in connection with the prevention of deterioration of cellulosic materials. The conditions needed to produce the enzyme in quantity have been defined, and mutant strains have been developed that produce 2 to 4 times as much cellulase as the wild strain. It is believed that the upper limit has not yet been reached.

As indicated earlier, the insolubility and crystallinity of pure cellulose and the presence of lignin in waste cellulose make it a most resistant substrate. The most satisfactory pretreatment found is ball milling. This reduces the crystallinity and particle size of the cellulose [4], and increases its bulk density, making it more reactive for saccharification.

METHODS

Methods used in this paper are described in ref. 4. The Filter Paper Cellulase Unit equals micromoles of glucose produced per minute from 50 mg of Whatman No. 1 paper incubated with cellulase at a pH of 4.8 at 50°C for one hour, and is based on the enzyme dilution to give 2.0 mg of reducing sugar as glucose. The CMC (C_x) cellulase unit equals micromoles of glucose produced per minute when the enzyme is incubated with 0.5% carboxymethyl cellulose (D.S. 0.50 manufactured by Hercules Powder Co.) at a pH of 4.8 at 50°C for 30 minutes, and is based on the enzyme dilution to give 0.05 mg of glucose.

EXPERIMENTAL RESULTS

Pestalotiopsis westerdijkii QM 381 (PW) produces a cellulase containing largely C_x [4]. Consequently, culture filtrates from this organism can hydrolyze only the amorphous or available portions of the cellulose. Figure 3 shows several substrates which have been hydrolyzed by broth containing C_x. From Fig. 3 the information shown in Table 1 is obtained. The data in Table 1 show the positive effect that ball milling has on increasing cellulase activity.

When these same substrates were hydrolyzed by the cellulase broth containing C_1 and C_x produced by *Trichoderma viride* QM 9414 (TV), the available or amorphous portion of the cellulose was hydrolyzed very rapidly [4]. Hydrolysis of the crystalline region followed at a less rapid rate. From Fig. 4 the information in Table 2 is obtained.

Total hydrolysis in 48 hours ranged from about 6 percent for fibrous cotton to over 90 percent for milled pulp, Sweco 270 [6]. Milled newspaper was 70 percent hydrolyzed. Since newspaper is 30 percent lignin [4], the 70 percent hydrolysis represents total hydrolysis of the cellulose content of the newspaper [4]. It is thus apparent that the rate and extent of hydrolysis depends both on the quality of the enzyme used, and the nature and the pretreatment of the substrate.

More conclusive evidence as to the significant effect C_1 has on the hydrolysis reaction is shown in Fig. 5. Using filter paper as the substrate and enzyme solutions with equal C_x activity as adjusted on carboxymethyl cellulose (CMC),

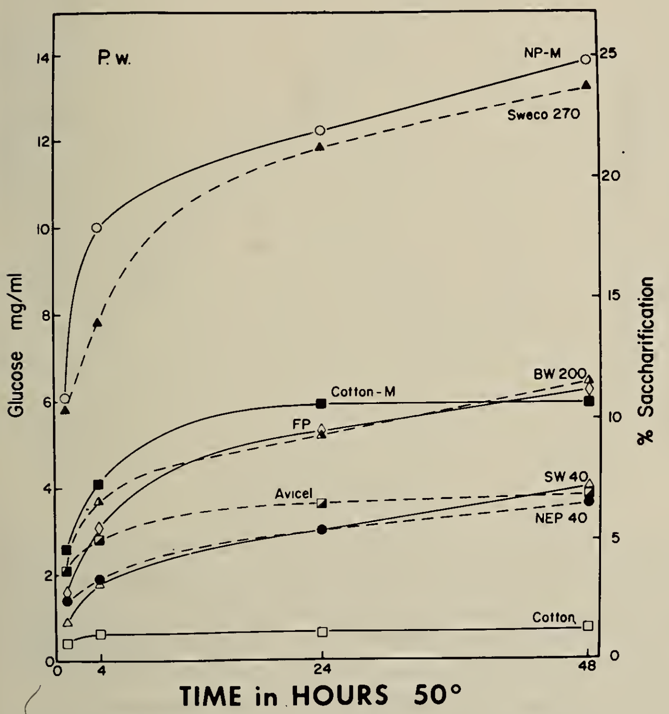

Fig. 3. Hydrolysis of insoluble cellulose by a C_x cellulase from *Pestalotiopsis westerdijkii.* (○) Newspaper, ground in a Sweco ball mill; (▲) pure cellulose pulp, ground to 270 mesh in a Sweco ball mill; (■) ball milled absorbent cotton; (▲) BW 200, a ball milled pulp prepared from SW40, 200 mesh, Brown Co., Berlin, N.H.; (◇) Whatman No. 1 filter paper; (◪) Avicel, microcrystalline cellulose, American Viscose Co.; (●) NEP 40, hammer milled uninked newsprint, 40 mesh; (△) SW40, hammer milled sulfite pulp, 40 mesh; (□) absorbent cotton, fibrous.

TABLE 1

Substrate	Available cellulose after 1 hour (%)	Saccharification after 48 hours (%)
Absorbent cotton, fibrous	0.7	1.3
Pure cellulose pulp SW 40	1.6	7.2
Hammer milled newsprint NEP 40	2.5	6.5
Whatman No. 1 filter paper	2.9	11.2
Avicel pH 105, microcrystalline cellulose	3.8	6.8
Ball milled absorbent cotton	4.7	10.6
Ball milled pure cellulose pulp BW 200	3.8	11.5
Pure cellulose pulp Sweco 270	10.4	23.8
Ball milled newspaper NP-M	10.4	24.9

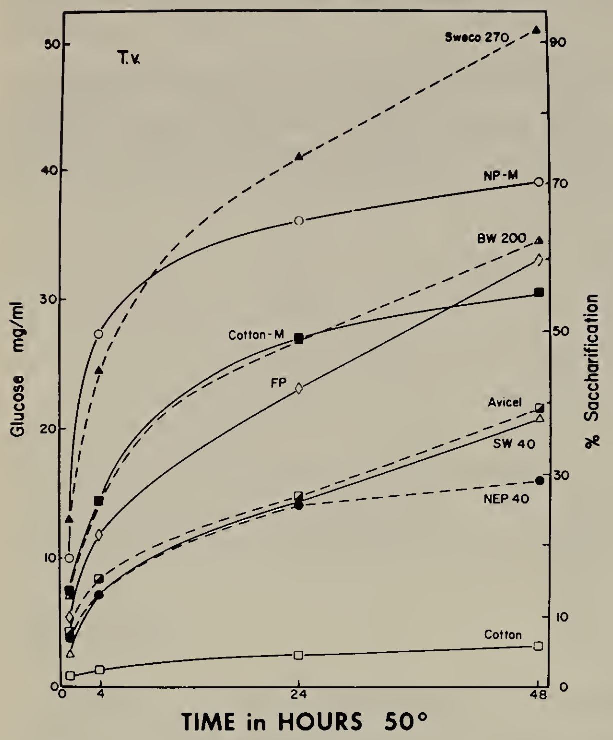

Fig. 4. Hydrolysis of insoluble cellulose by a complete cellulase from *Trichoderma viride*. (○) Newspaper, ground in a Sweco ball mill; (▲) pure cellulose pulp, ground to 270 mesh in a Sweco ball mill; (■) ball milled absorbent cotton; (▲) BW 200, a ball milled pulp prepared from SW40, 200 mesh, Brown Co., Berlin, N.H.; ( ) Whatman No. 1 filter paper; (◪) Avicel, microcrystalline cellulose, American Viscose Co.; (●) NEP 40, hammer milled uninked newsprint, 40 mesh; (△) SW40, hammer milled sulfite pulp, 40 mesh; (□) absorbent cotton, fibrous.

TABLE 2

Substrate	Available cellulose after 1 hour (%)	Saccharification after 48 hours (%)
Absorbent cotton, fibrous	1.4	6.0
Pure cellulose pulp SW 40	4.7	37.4
Hammer milled newsprint NEP 40	6.8	28.8
Whatman No. 1 filter paper	9.7	59.4
Avicel pH 105, microcrystalline cellulose	7.0	39.6
Ball milled absorbent cotton	13.5	54.9
Ball milled pure cellulose pulp BW 200	12.8	62.1
Pure cellulose pulp Sweco 270	23.4	91.8
Ball milled newspaper NP-M	18.0	70.0

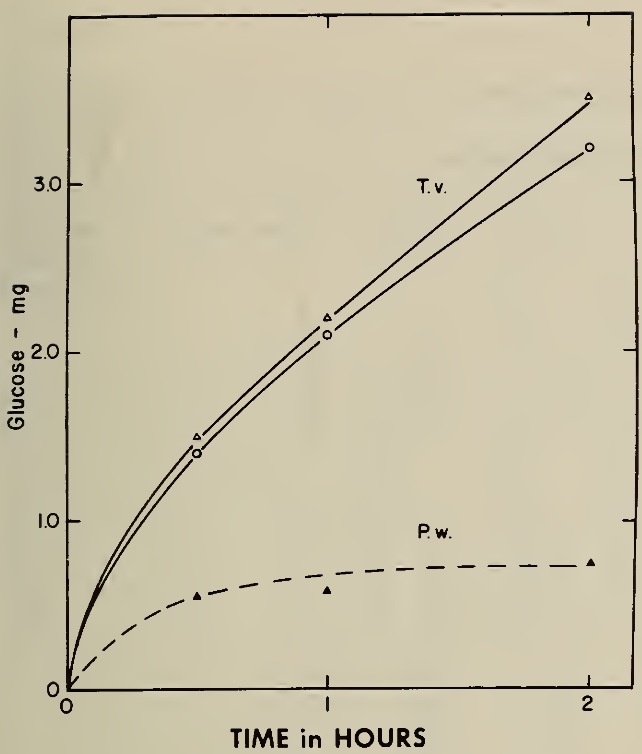

Fig. 5. Hydrolysis of filter paper by cellulase preparations from *Trichoderma viride* and *Pestalotiopsis westerdijkii* adjusted to equal activities on carboxy methyl cellulose (19 C_x units/ml). (△) Tv QM 9123 culture filtrate; (○) Tv QM 9414 culture filtrate; (▲) Pw QM 381 culture filtrate.

the concentration of glucose produced as a function of time was determined. The results show that the enzyme solution containing both C_1 and C_x produced 5 to 6 times more glucose than the enzyme solution containing only the C_x component. The C_x (PW) enzyme rapidly hydrolyzes the limited amorphous portion of the substrate, after which the hydrolysis stops since it cannot attack the crystalline portion of the substrate. The $C_1 + C_x$ (TV) cellulase attacks the amorphous portion rapidly and then continues to hydrolyze the crystalline cellulose at a slower rate.

Table 3 shows the hydrolysis of a number of pure and waste celluloses by the culture filtrate of *Trichoderma viride.* Saccharification is slow for crystalline cellulose such as cotton, untreated rice hulls or bagasse but milling will greatly increase their reactivity. Shredded or milled papers also make good substrates. The fiber fraction separated by the Black-Clawson hydropulping operation of municipal trash [4] is an excellent substrate material, especially after milling. The same is true for the shredded cellulose fraction of municipal trash which is separated by air classification, using the Bureau of Mines resources recovery process [4]. Waste cellulose from municipal trash is of particular interest because such waste will be increasingly available in large quantity.

Pretreatment of the substrate is an important variable which will affect not only the degree of saccharification, but also the economics of the process. Using newspaper as a model substrate, various substrate treatments were tried. The results are shown in Table 4. It should be noted from these studies that milling the substrate gave the best results.

TABLE 3

Hydrolysis of cellulose by *Trichoderma viride* cellulase

Substrate	% Saccharification			
	1 hr	4 hr	24 hr	48 hr
Pure cellulose				
Cotton — fibrous	1	2	6	10
Cotton — pot milled	14	26	49	55
Cellulose pulp SW40	5	13	26	37
Milled pulp Sweco 270	23	44	74	92
Waste cellulose				
Bagasse	1	3	6	6
Bagasse — pot milled	14	29	42	48
Corrugated fibreboard Mighty Mac	11	27	43	55
Corrugated fibreboard pot milled	17	38	66	78
Black Clawson fibers	5	11	32	36
Black Clawson pot milled	13	28	53	56
Bureau of Mines cellulose	7	16	25	30
Bureau Mines pot milled	13	31	43	57

TABLE 4

Pretreatment of newspaper

	% Saccharification			
	1 hr	4 hr	24 hr	48 hr
Boiled in water	4	9	21	26
Cuprammonium	18	35	52	58
Fitzpatrick (hammer mill)	10	16	25	28
Gaulin (colloid mill)	9	17	27	31
Granulator-comminutor	6	14	24	26
Jay Bee-paper shredder	6	12	24	27
Majac (jet pulverizer)	11	15	26	29
Mighty Mac-Mulcher	10	24	31	42
Pot mill	18	49	65	70
Soaked in water	7	13	24	28
Sweco mill	16	32	48	56
Treated 2% NaOH	8	14	28	35
Viscose	15	30	44	51

Because of its specificity, the cellulase enzyme reacts solely with the cellulose and does not react with other materials or impurities present in the waste. Table 5 shows the results achieved with milled newspaper digested in a stirred tank reactor. Glucose syrups of 2 to 10 percent concentrations were obtained. The ink, lignin, and other impurities present did not cause any problems [7].

TABLE 5

Hydrolysis of milled newspaper in stirred reactors

Reactor volume 1 liter, stirred 60 rpm, pH 4.8.

Enzyme protein (mg/ml)	Newspaper (%)	Temp (°C)	Glucose				Saccharification (%)
			1 hr (%)	4 hr (%)	24 hr (%)	48 hr (%)	
0.7	5	50	1.0	2.0	2.8	—	50
0.7	5	50	1.0	2.0	2.3	—	42
1.0	10	50	2.1	3.1	5.5	7.3	66
1.6	10	45	2.0	3.6	5.4	6.5	59
1.6	10	50	2.3	4.2	6.4	6.3	57
0.8	15	45	1.5	2.8	5.3	7.7	46
0.8	15	50	0.8	2.8	6.1	6.3	38
1.8	15	50	3.2	6.0	8.6	10.0	60

The residue after hydrolysis was a black sticky material that dried to a hard nonwettable cake. This material is chiefly lignin which can be burned as a fuel or used as a source of chemicals [4].

Results achieved with newspaper show that it is technically feasible to produce glucose syrups in good yield (40—50 percent) and at a practical rate from waste cellulose. Newspapers were selected as the model substrate since such waste is representative of most cellulosic waste present in municipal trash.

In addition to those wastes shown in Table 3, several other industrial and agricultural wastes have been evaluated and classified as potential substrates for hydrolysis [7]. Using ball milled newspaper as representative of all wastes that could be used in the process, the degree of saccharification of other wastes tested relative to ball milled newspapers are listed in Tables 6 and 7. Substrates whose relative value is 1.0 or better are considered good substrates for hydrolysis.

Milling of the substrate to reduce its crystallinity is an energy-intensive and costly process. Consequently, an intensive search for other physical, chemical or combinations of both treatments must be explored to optimize the economics of the overall process.

A potential approach to reducing the cost of substrate pretreatment may be the substitution of other pulp refining methods for the ball milling operation. Preliminary studies with pulped government documents show that pulping may be very effective as a substrate pretreatment. Saccharification studies using hydropulped substrates at three cellulose slurry concentrations and at three enzyme activity levels were conducted, and the results are shown in Table 8. The weight of glucose and percent saccharification realized as a func-

TABLE 6

Wastes for conversion

Saccharified at 50°C, pH 4.8, with *T. viride* QM 9414 cellulase 1.2 units/ml.

Substrate 5% dry wt.	Relative % saccharification 24 hours[a]		
	As rec'd wet	As rec'd dry	Ball milled
Pure			
Cotton	—	0.1	0.9
Filter paper	—	0.8	—
Cellulose pulp	—	0.5	1.4
Agricultural			
Rice hulls	—	0.03	0.4
Bagasse (sugar cane)	—	0.09	0.9
Rumen fibers (manure)	0.2	0.3	1.0
Paper			
Corrugated fibreboard	—	0.9	1.1
Computer print out	—	0.9	1.4
Key punch holes	—	0.8	—
Milk carton (polyethylene coat)	—	1.0	1.1
Newspaper	—	0.6	1.0
Municipal trash fractions			
Black Clawson	0.7	0.7	1.2
Bureau Mines	—	0.6	0.9

[a] Relative to ball milled newspaper (56% sacch.) = 1.0. Substrates whose relative value is 1.0 or better are considered good substrates for hydrolysis.

tion of reaction time at three enzyme activity levels are shown in Figs. 6, 7, and 8. Figure 9 shows the weight of glucose produced and percent saccharification realized as a function of enzyme activity level for a fixed reaction time of twenty-four hours. Final glucose concentrations ranged between 1.6 to 4.6 percent and increased with either enzyme activity or substrate concentration. Final saccharification ranged from 33 to 77 percent and increased with enzyme activity, but decreased as the substrate concentration increased.

Milling, rather than chemical pretreatment, is preferred by the authors for increasing the reactivity of the raw materials. The costs of milling and chemical pretreatment are approximately the same. The encouraging results obtained with hydropulped substrates may prove to be most significant in cutting substrate pretreatment costs, thereby improving the overall economics of the process.

Having proved that this process is technically feasible, the Natick Development Center is conducting an intensive pre-pilot plant study to optimize all variables and to obtain the engineering and economic data needed for the design of a demonstration plant. The pre-pilot plant was engineered in collab-

TABLE 7

Industrial wastes for conversion

Saccharified at 50°C, pH 4.8 with *T. viride* QM 9414; cellulase 0.08—1.5 w/ml (ave. 1.0).

Substrate 5% dry wt.	Relative % saccharification 24 hours[a]		
	As rec'd wet	As rec'd dry	Ball milled
Percent saccharification ≥ 1 as received			
22 Nicolet sulfite pulp	1.2	0.8	1.7
15 Hydropulped Govt. documents	1.3	1.3	1.5
16 Hydropulped Govt. documents	1.1	0.9	1.5
21 Nicolet kraft pulp	—	0.8	1.5
12 Kimberly Clark tissue mill waste	1.0	1.0	1.1
1 St. Regis paper mill sludge	1.0	0.9	0.9
2 St. Regis glassine (PVD) waste	—	0.8	0.9
3 St. Regis glassine (wax) waste	—	0.8	0.6
Percent saccharification ≥ 1 if ball milled			
13 Cotton linters (miles)	—	0.2	1.3
18 Corey paper mill waste	0.5	0.3	1.2
14 Extracted oat hulls (Hoffman La Roche)	—	0.1	1.2
20 Nicolet waste filler	0.6	0.5	1.1
23 Rye grass straw (Miles)	—	0.3	1.1
17 Covey paper mill waste	0.6	0.5	1.0
26 Hercules wood chips	—	0.1	1.0
25 Welches seedless grape pomace	—	0.6	0.9
19 Stuley corn fiber	—	0.3	0.8
24 Welches grape pomace	—	0.5	0.7

[a]Relative to ball milled newspaper (ave. 42% sacch.) = 1.0.

TABLE 8

Hydrolysis of hydropulped Government documents in 1 liter Str, 50°C, pH 4.8

Sample No.	Enz. conc. (u/ml)	S conc. % dry wt.	Hydrolysis at 24 hrs	
			Glucose (mg/ml)	Saccharification (%)
15	0.5	2.3	16	64
16	0.5	4.8	23	43
16	0.5	7.7	26	30
16	1.0	2.3	20	77
16	1.0	5.0	33	59
16	1.0	7.5	39	47
16	1.5	2.4	21	79
16	1.5	5.2	39	67
16	1.5	7.8	46	53

Enz. = cellulase of *T. viride* QM 9414; S = pulped documents as rec'd, wet;

$$\% \text{ Saccharification} = \frac{\text{glucose mg/ml} \times 0.9}{5 \text{ mg/ml (original)}} \times 100.$$

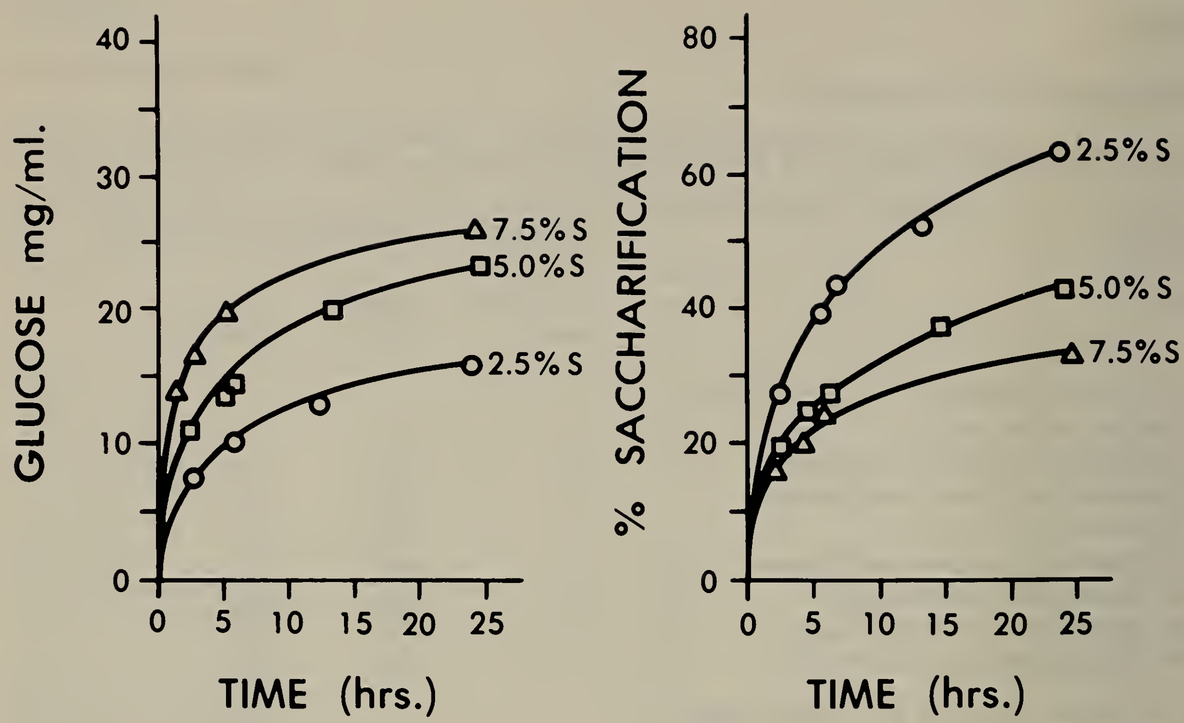

Fig. 6. Hydrolysis of hydropulped Gov't documents by *Trichoderma viride* cellulase. $[E]$ = 0.5 units/ml (FP).

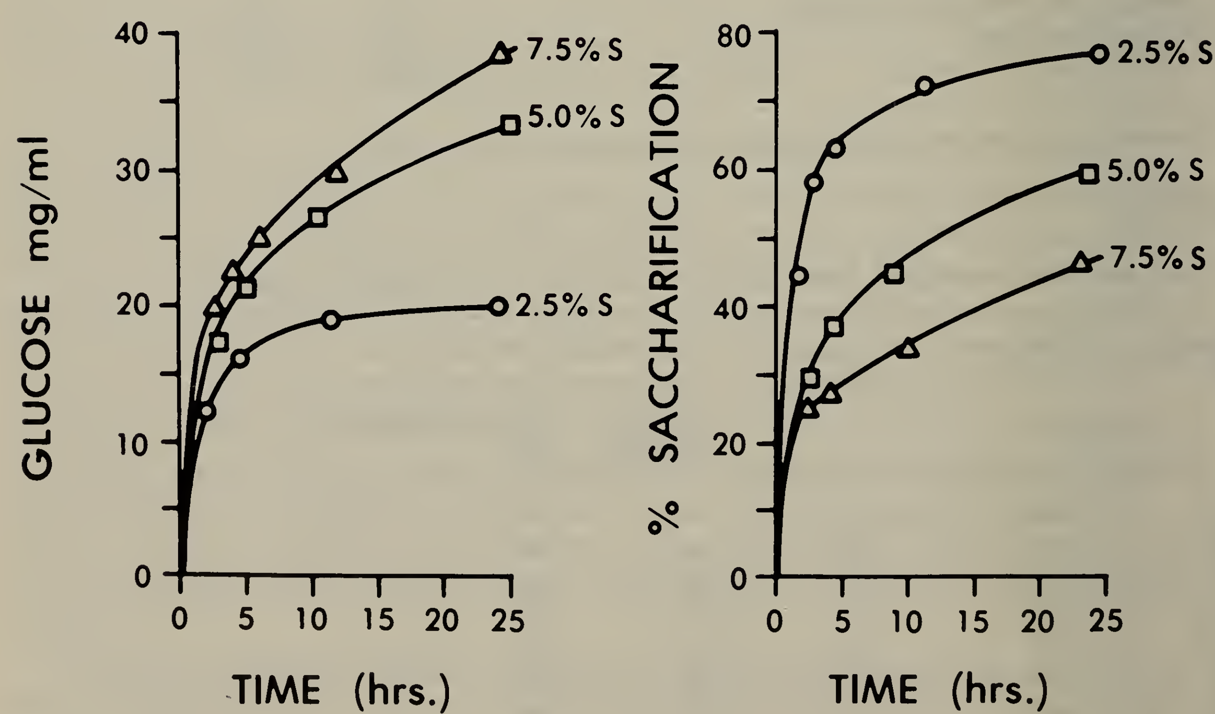

Fig. 7. Hydrolysis of hydropulped Gov't documents by *Trichoderma viride* cellulase. $[E]$ = 1.0 units/ml (FP).

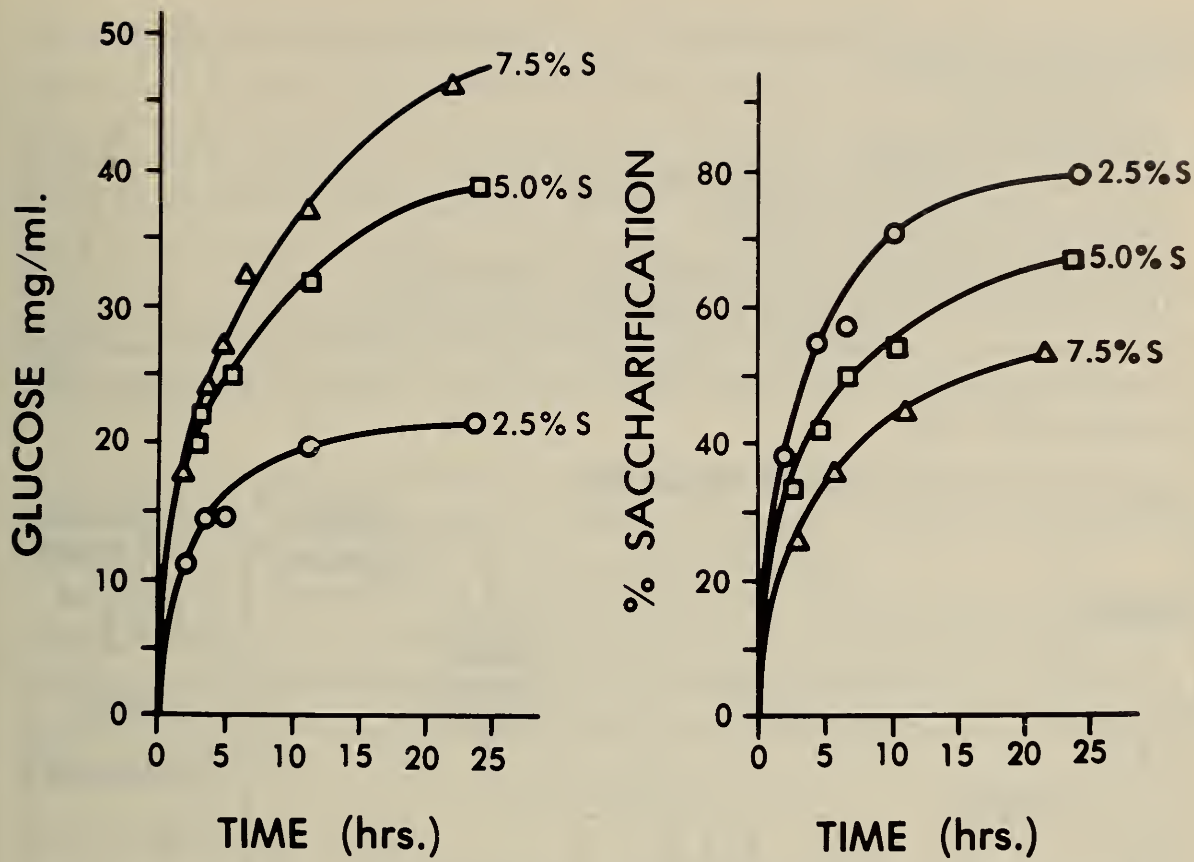

Fig. 8. Hydrolysis of hydropulped Gov't documents by *Trichoderma viride* cellulase. $[E]$ = 1.5 units/ml (FP).

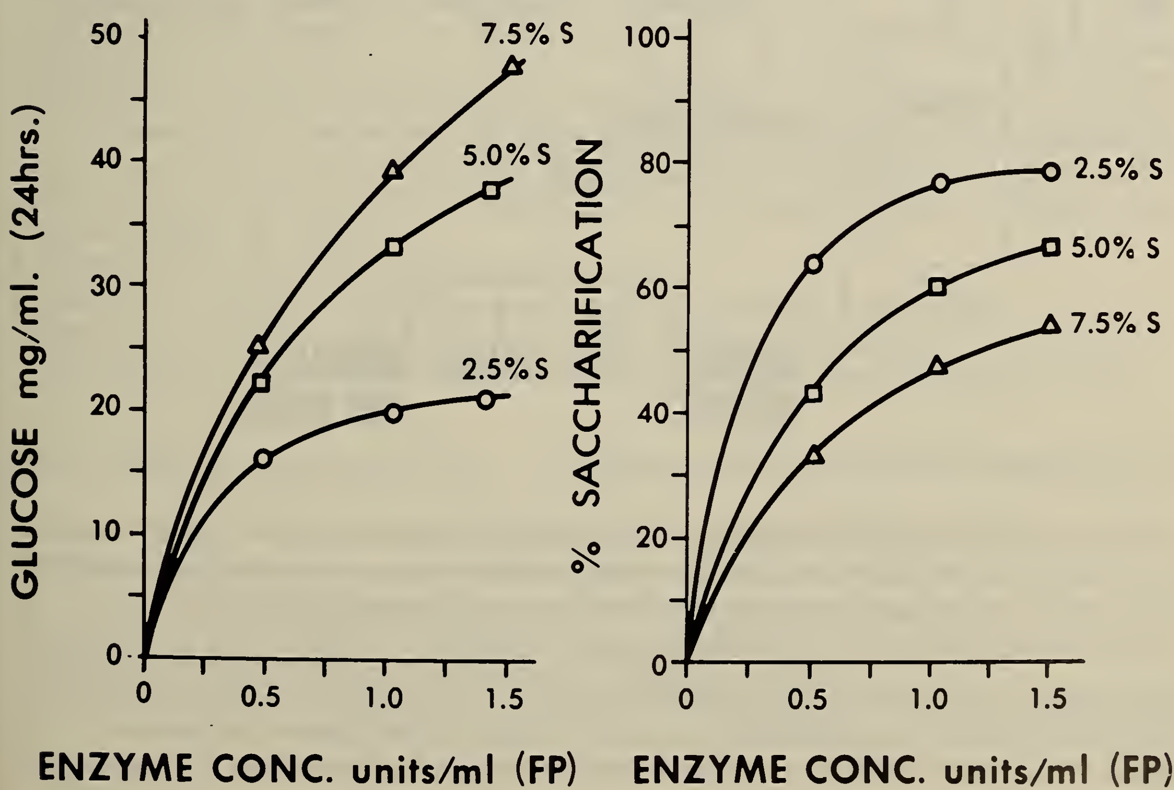

Fig. 9 Relationship of *T. viride* cellulase activity level to 24 hour glucose yield and percent saccharification in the hydrolysis of hydropulped Gov't documents.

oration with Fermentation Design, Inc. of Bethlehem, Pa., and comprises the following equipment:

(1) Fermenters
(2) Enzyme reactors
(3) Holding tanks and auxiliary vessels
(4) Instrumentation modules
(5) Substrate handling and preparation equipment
(6) Enzyme recovery and concentration equipment

The design and construction is such that the most sophisticated fermentation techniques including batch, continuous, and semi-continuous processes can be studied (Fig. 10).

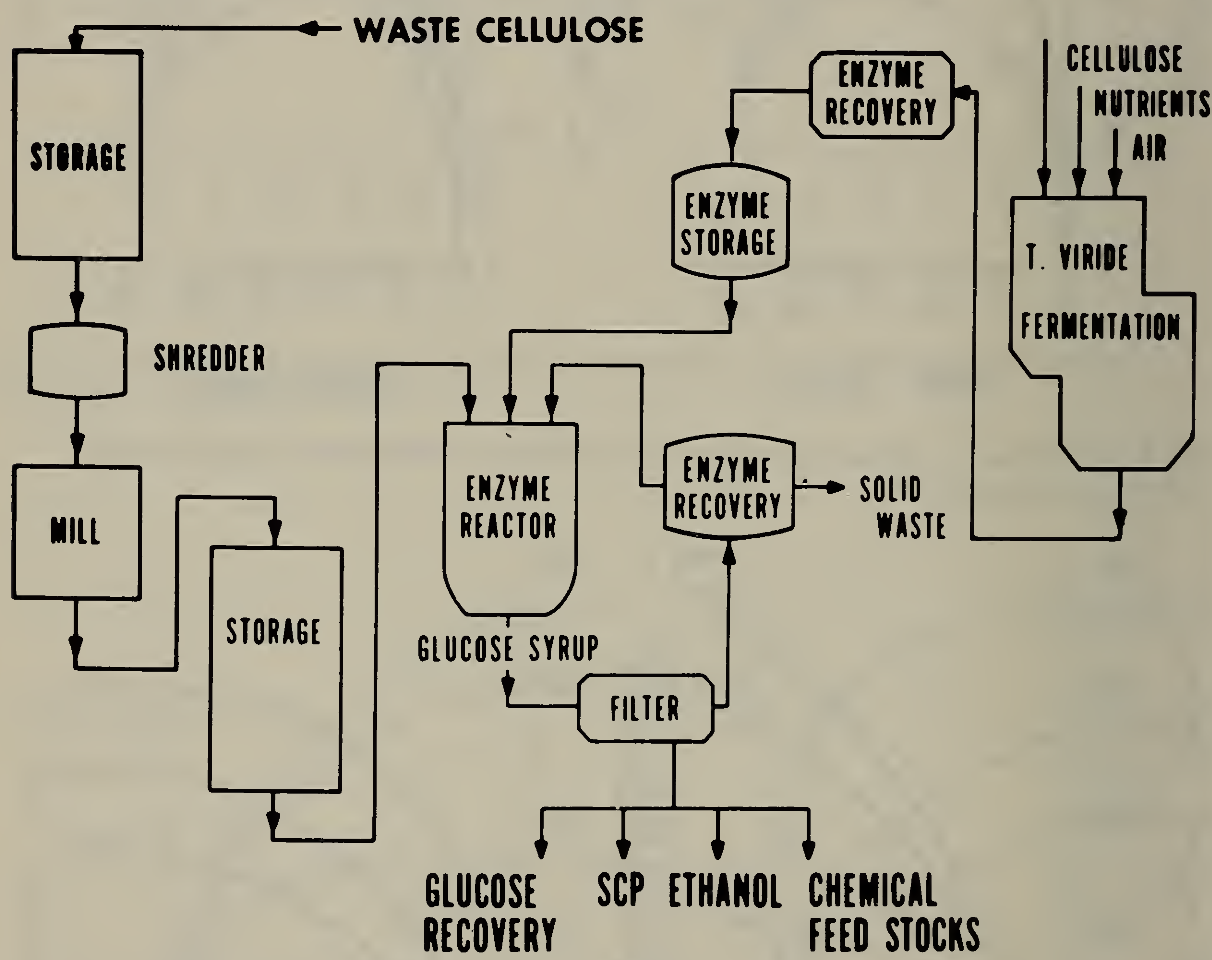

Fig. 10. Enzymatic conversion of waste cellulose.

Because of the sophistication of the monitoring and control instrumentation, both fermentation and enzyme hydrolyses are continuously monitored and controlled to optimize the output of the individual processes.

The initial capacity of this equipment is 1000 lbs. of cellulose per month. With minor modifications the capacity may be increased possibly four-fold. This equipment is now operational at the Natick Development Center.

The potential world-wide impact of this process on the food, energy and ecology problems has been recognized both nationally and internationally.

Upon completion of these studies, it will be possible to engineer larger pilot demonstration plants and possibly full scale plants with confidence. Many national and international chemical companies, pulp and paper mills, processors of agriculture products and various governments have shown definitive interest in the exploitation of this process. Because of this interest, the U.S. Army Natick Development Center is working very closely with several industrial firms to assure the transfer of this new technology to commercial scale as soon as practicable for the benefit of the nation and mankind.

CONCLUSIONS

(1) The enzymatic hydrolysis of cellulose is technically feasible and practically achievable on a large scale by 1980. The glucose produced can be converted to food products, fuel and chemical feedstocks.

(2) The exploitation of our fossil fuel reserves — coal, oil shale, etc. — may satisfy our energy demands for the next five to ten decades. However, the ultimate long-range solution to the world's energy problem may well be the development of practical and economical processes to harness the inexhaustible energy of the sun.

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ENERGY FROM REFUSE BY BIOCONVERSION, FERMENTATION AND RESIDUE DISPOSAL PROCESSES *,**

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ABSTRACT

Biological conversion of organic refuse to methane by anaerobic fermentation is one mechanism by which the energy in urban waste can be reclaimed. Laboratory studies have been used to determine the rate and quantity of gas production at various operating temperatures. The dewatering characteristics of the spent fermentation slurry have been evaluated. The spent solids can be dewatered to a sufficiently low moisture content such that incineration is selfsustaining. The incineration system has been evaluated to determine the possible energy recovery from the spent cake. A process for treating the liquid blowdown from the system has been developed.

A mathematical simulation of the total system has been constructed to evaluate performance under various operating conditions. The operating cost of the system can be obtained. A plant processing 908 metric tons of refuse per day will produce 3905 m^3 of methane per hour. If the methane is marketed for \$3.53/100 m^3, the system will require a dump fee for refuse disposal in excess of \$5.34/metric ton. Sale of recovered steam from the incineration of the spent cake can reduce the dump fee by about \$3.00. Recovery of just methane provides an efficiency of energy recovery of 32.6 percent. This efficiency can be increased to 63.4 percent if the steam from the incinerator can be sold.

INTRODUCTION

Among the many challenges confronting the world as a whole, and the United States in particular, are two seemingly unrelated problems. The first and perhaps the more obvious of the two is the problem of solid waste disposal. The second is the decline in certain energy resources as evidenced by the increasing shortage in natural gas reserves. The development of a process to convert organic refuse to methane would provide at least a partial solution to both of these problems.

Anaerobic digestion has been used for decades in wastewater treatment to

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effectively reduce the quantity of organic sludges and to transform them into stable, more easily dewatered residues. The reduction is accomplished by the biological conversion of the organic solids to methane and carbon dioxide. Since anaerobic processes have a very low efficiency of biological energy conversion, most of the energy of the substrate is lost. The gas produced has a high energy content and is a valuable end product with potential for reclamation.

Various studies have demonstrated that organic refuse, in particular garbage, is amenable to anaerobic decomposition. Organic refuse is composed basically of the same compounds (carbohydrates, proteins and fats) as sewage sludge, though in different relative proportions. There appears to be no reason why refuse cannot undergo adequate anaerobic decomposition. Proper environmental conditions must be maintained, the deficient nutrients supplied and potential toxicity problems controlled.

Using existing technologies developed for producing refuse derived fuel (RDF), it is possible to produce a light fraction that can be used as substrate for the anaerobic fermentation process. Laboratory studies were conducted to evaluate the quantity and rate of gas production, reactor slurry dewatering characteristics, and residue disposal. Data obtained from these studies, plus those available in the literature, were used to construct a mathematical simulator of the entire process. This simulator was used to evaluate the performance of the system under various operating conditions.

QUANTITY AND RATE OF GAS PRODUCTION

To determine if a biological process could be developed that would effectively convert municipal refuse to methane, a series of laboratory studies was undertaken to establish the kinetic relationships at various operating temperatures. This work is discussed in detail elsewhere [1—3]. The pertinent results are shown in Fig.1 and Table 1. Figure 1 shows the gas production (dry gas

TABLE 1

Volatile solids destruction (percent)[a]

Temperature (°C)	Retention time (days)						
	4	6	8	10	15	20	30
35	16.5	26.4	28.6	29.8	32.0	32.7	34.0
40	31.0	33.6	35.7	36.8	39.0	39.9	40.7
45	26.7	29.0	31.2	32.3	34.1	35.4	36.4
50	34.9	38.6	41.0	42.2	44.2	45.4	46.1
55	40.4	42.6	44.5	45.2	47.2	48.2	49.1
60	41.9	46.6	48.3	49.6	50.8	51.8	52.4

[a] Percentage of organic material in the raw refuse that is converted to gas.

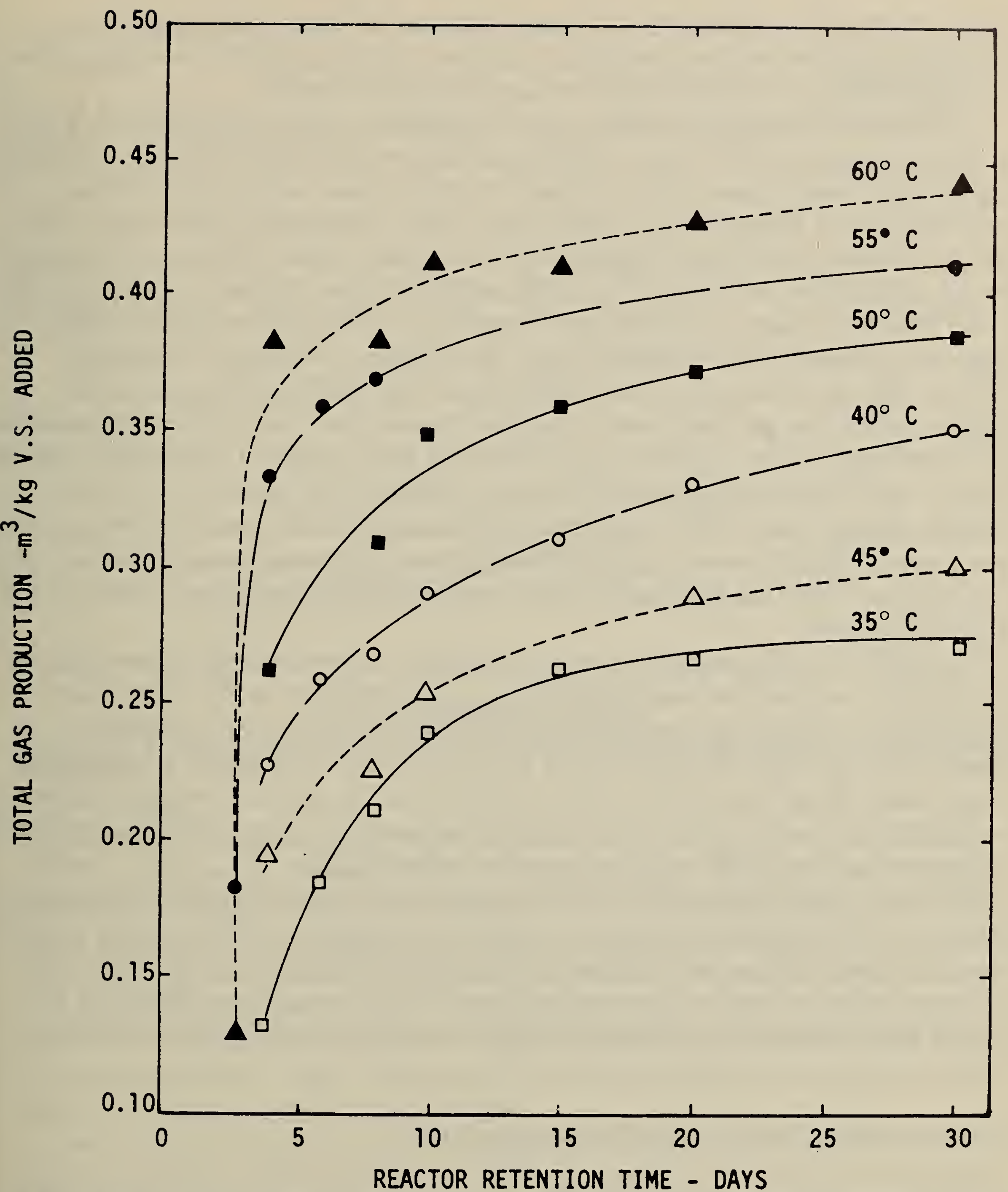


Fig. 1. Gas production obtained from the digestion of municipal refuse (dry gas at 0°C and atmospheric pressure).

at 0°C and atmospheric pressure) obtained at various temperatures and retention times. The substrate used in these studies was shredded refuse obtained from the USEPA Center Hill Laboratory in Cincinnati, Ohio. The volatile solids destruction in Table 1 was calculated from the gas production. Because of the characteristics of the substrate and the laboratory reactors employed, it was not possible to obtain the solids balance necessary to measure volatile solids destruction accurately. It is important to note that the maximum volatile solids destruction was only 52.4 percent. A significant portion of the material added to the fermenter remains for final disposal.

The original laboratory studies used completely mixed digesters having an operating volume of 15 liters. Additional data were collected from a 400-liter digester that was operated at a 10-day retention time and at 60°C. When refuse obtained from a local landfill was used as substrate for the larger unit, gas production was 0.39 m^3/kg (6.3 scf/lb) volatile solids added as compared to gas production of 0.40 m^3/kg (6.55 scf/lb) for the 15 liter units operating at 60°C and a 10-day retention time (see Fig.1). However, when the large digester received refuse obtained from the Madison, Wisconsin shredding facility, the gas production was only 0.32 m^3/kg (5.22 scf/lb) of volatile solids added. The gas yield was 18 percent lower than that previously obtained from the large reactor. When refuse obtained from the St. Louis-Union Electric project was used, the gas production was only 0.31 m^3/kg (5.0 scf/lb) of volatile solids added. This low gas production apparently resulted from aerobic composting that occurred while the wet refuse was being transported and dried for storage. While gas production may vary with feed stock, the variation will not be excessive.

The effect of temperature on gas production is pronounced. The optimum mesophilic temperature was found to be about 40°C. At 43°C, inhibition of gas production was significant. Gas production at 45°C was only slightly greater than at 35°C. The maximum gas yield in the mesophilic temperature range was 0.29 m^3/kg (4.65 scf/lb) of volatile solids added. The gas yield was substantially greater in the thermophilic temperature range, with the maximum being 0.45 m^3/kg (7.25 scf/lb) of volatile solids added.

The rate of gas production is much greater in the thermophilic temperature range. At 60°C the gas yield from a system operating at a 4-day liquid retention time was about 85 percent of that obtained at a 30-day retention time. The gas production at the 4-day retention time (60°C) was greater than that obtained from digesters operating at 40°C temperature and 30-day retention time.

SLURRY DEWATERING—VACUUM FILTRATION

The characteristics of the digester slurry, in particular the dewaterability, were investigated. Laboratory evaluation of the vacuum filtration system was conducted using the filter test leaf technique. The results of these studies are shown in Fig.2. A coarse weave filter cloth was employed. No chemicals were used to condition the slurry before dewatering. Solids capture was not high, but since a major portion of this filtrate is expected to be recycled, high solids capture was not considered to be important.

Exceptionally high filter cake yields can be obtained from vacuum filters if the solids concentration in the feed slurry is high and a dry cake is not required However, if it is necessary to produce cake with a low moisture content, the

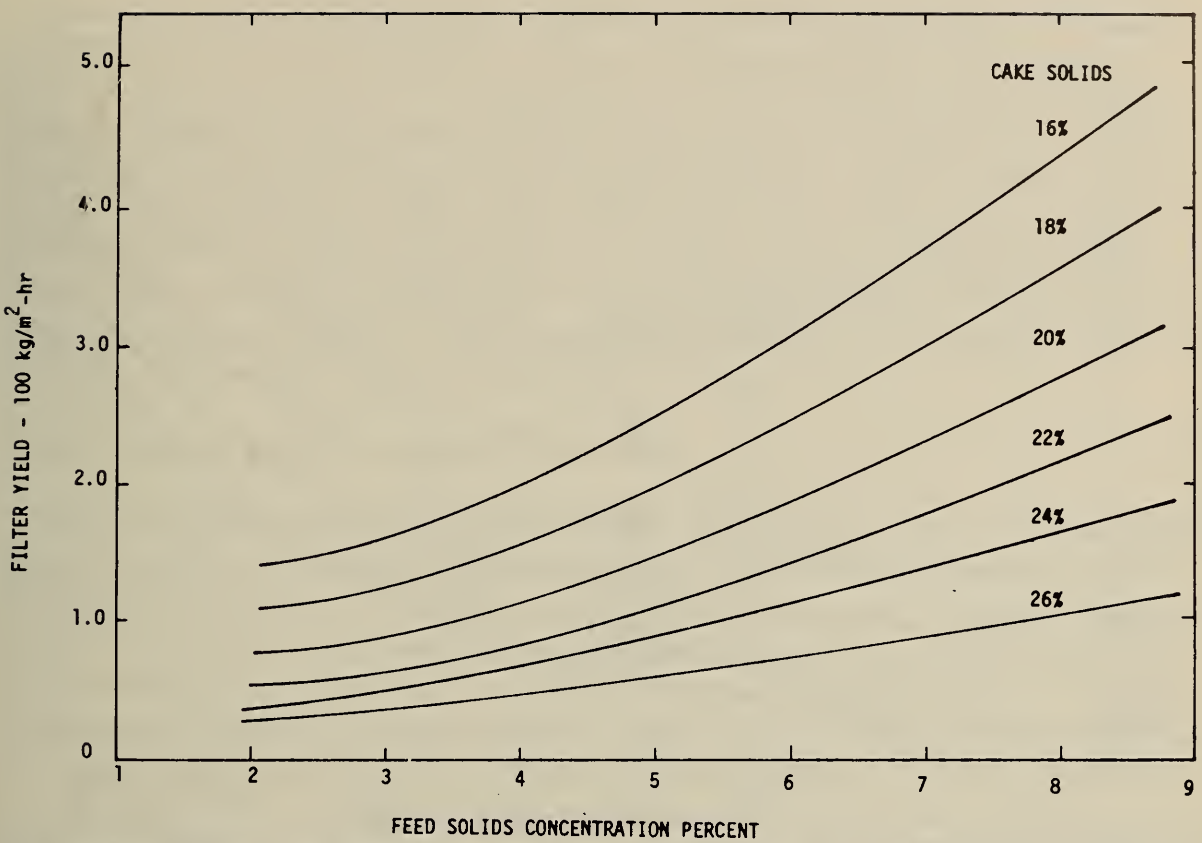


Fig. 2. The effect of feed solids concentration and cake solids on filter yield, no chemical conditioning.

loading on the filter is greatly reduced. The addition of a polymer (Nalco 73C32) significantly improved the dewatering characteristics. These results are shown in Fig. 3. With unconditioned slurry at 3 percent feed solids, filter yields of 48.8 and 97.6 kg/m^2-hr (10 and 20 lbs/ft^2-hr) resulted in a cake with a solids content of 24 and 20 percent, respectively. With conditioned slurry at the same feed concentration, a filter yield of 48.8 kg/m^2-hr was achieved with a cake containing 30 percent solids, and a filter yield of 97.6 kg/m^2-hr was achieved with a cake containing 27.5 percent solids, both substantial increases over the unconditioned slurries.

The polymer dosages used in the first series of test runs were based on the fine suspended solids in the feed and these dosages were chosen on the basis of specific resistance values determined in preliminary work [4]. The dosages used were not necessarily optimum. To determine the approximate optimum dosage, a series of tests was run with 3.3 percent feed solids using a 30-second form time and 3-minute dry time, and varying the polymer dosage from 0 to 5.4 percent. The results of these tests are given in Table 2. From these data it would seem that the optimum dosage at 3-percent feed solids was about 2 percent. There was no substantial improvement in filtrate suspended solids or cake solids as higher dosages were used.

While the results clearly show the advantages of using polymers to improve vacuum filtration results, the costs associated with polymer use must be con-

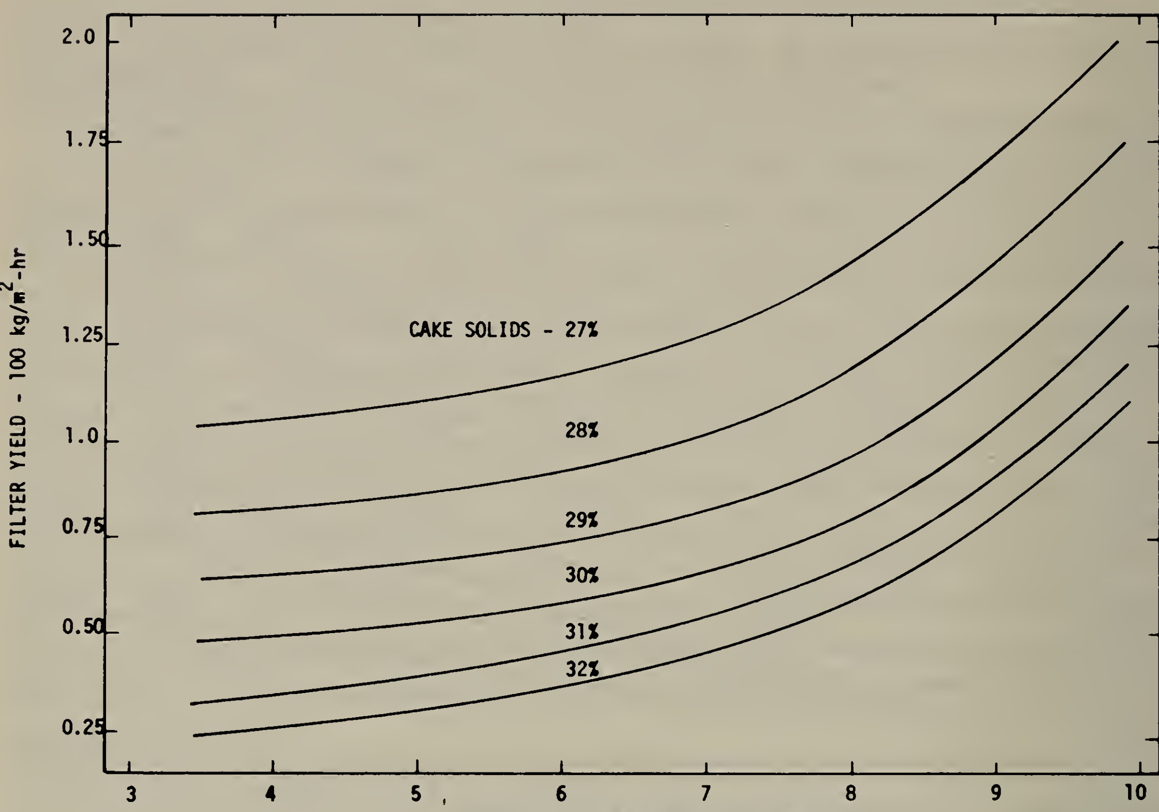


Fig. 3. The effect of feed solids concentration and cake solids on filter yield when slurry was conditioned with polymer (Nalco 73C32).

TABLE 2

Optimization of polymer dose for 3.3% feed solids[a]

Polymer dose (% of FSS)	Form rate (kg/m^2-hr)	Filter yield (kg/m^2-hr)	Cake solids (%)	Filtrate solids (g/l) TS	SS	DS
0.00	121	17.3	27.8	10.05	6.42	3.63
1.09	163	23.3	29.3	6.05	2.77	3.27
2.17	169	24.2	31.1	3.79	0.55	3.24
3.26	185	26.4	31.6	3.35	0.14	3.21
4.35	166	23.8	33.0	3.76	0.65	3.11
5.43	161	23.0	33.6	3.24	0.23	3.01

[a] FSS = feed suspended solids, TS = total solids, SS = suspended solids, DS = dissolved solids.

sidered. Since vacuum filtration is only one step in the total system, the impact of this process on the remaining processes must be considered. High filter cake solids will reduce the cost of auxiliary fuel for residue incineration, or the haul and landfill costs if the residue goes directly to a landfill. Also, an increase in filter yield will reduce vacuum filter costs. The cost of the polymer must be offset by the cost reductions.

The following conditions were assumed in evaluating the cost of polymer conditioning of the slurry prior to vacuum filtration. With a feed slurry of 6 percent, a filter yield of 56.1 kg/m^2-hr (11.5 lbs/ft^2-hr) at 25 percent cake solids would be expected with unconditioned slurry. Conditioning the slurry with polymer (1.25 percent of feed suspended solids) would increase the cake solids to 30 percent at a filter yield of 56.1 kg/m^2-hr. With polymer priced at $0.66/kg ($0.30 per lb), the polymer cost alone would be $2.30 per metric ton of refuse received or $87.30 per hour for a 908 metric-tons-per day system. The savings possible in the downstream process do not warrant such cost. This will be discussed later in more detail.

SLURRY DEWATERING — CENTRIFUGATION

Dewatering tests were conducted using a solid bowl conveyor (model P-600 Super-D-Canter) centrifuge unit obtained on loan from the Sharples Division, Pennwalt Corporation. This unit was tested using the slurry from the 400 liter reactor. The slurry was pumped from a mixed storage tank to the centrifuge at a constant rate with a Moyno positive displacement pump. The centrifuge was operated for one to two minutes at each test condition prior to sampling the cake and the centrate. The machine was operated at 5700 rpm, producing a centrifugal force of approximately 3200 $\times$ *g*. The results are shown in Table 3 and Fig. 4.

Based on these data, a full scale machine of similar characteristics could process a maximum flow of 0.85 m^3/min (226 gpm), or a maximum solids loading ranging from 1476 kg/hr (3251 lbs/hr) per machine for a cake solids of 38.3 percent to 2099 kg/hr (4624 lbs/hr) per machine for a cake solids of 27 percent. As can be seen from Fig. 4, the conveyor speed relative to the centrifuge bowl speed was the major factor in determining the cake solids. An increase in the flow rate had little or no effect on the cake solids at a conveyor speed of 10 rpm. However, the solids loading does play a major role as the solids-flow rate approaches the machine capacity. From these observations, it appears that the solids-handling capacity of the machine limits the concentration of solids in the cake, particularly when the reactor slurry contained 5 percent or more solids.

Solids capture was not high in these tests, ranging from a low of 63 percent to a high of 90 percent. This high carry-over was a result of the presence of a substantial concentration of fine solids present in the slurry as well as poor capture of the fibers under certain test conditions. Chemical conditioning would improve this capture, but at a cost. Since this liquid is expected to be recycled back into the fermentor, solids capture is of limited significance.

RESIDUE INCINERATION

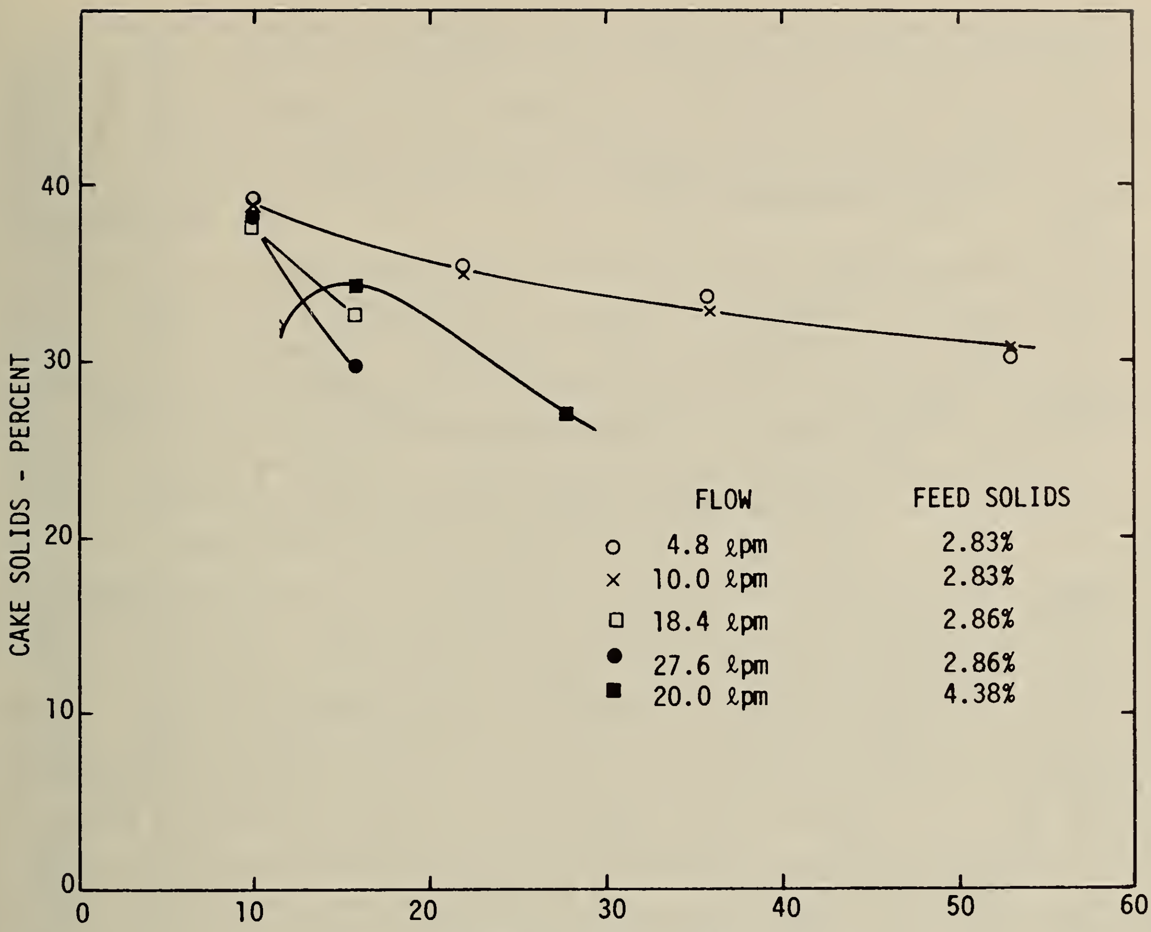
The ability to produce a cake with solids concentrations of 30 percent or greater with the centrifuge system has substantially improved the economics

TABLE 3

Sharples P-600 centrifuge results

Flow (lpm)	Conveyor speed (rpm)	Cake solids (%)	Centrate solids (g/l)		Suspended solids capture (%)
			Total	Suspended	
Pond setting 3½, feed total solids 28.3 g/l					
4.9	10	38.5	—	—	—
	22	34.9	—	—	—
	36	32.8	—	—	—
	53	30.6	—	—	—
10.0	10	39.4	—	—	—
	22	35.5	8.26	5.06	80.6
	36	33.8	9.45	5.94	77.6
	53	30.3	8.78	5.26	80.0
Feed total solids 28.6 g/l					
18.5	10	37.6	11.08	7.03	72.7
	16	32.7	11.10	6.93	73.3
27.6	10	38.3	11.43	7.17	71.9
	16	29.7	11.40	7.15	72.3
Feed total solids 21.4 g/l					
9.8	16	32.5	9.50	5.20	70.4
13.2	16	30.3	9.86	5.51	68.7
16.7	16	31.2	11.22	6.44	63.5
20.1	16	33.6	11.20	6.50	62.8
Feed total solids 43.8 g/l					
20.1	10	No separation, solids overload			
	16	34.2	12.44	7.40	82.6
	28	27.0	10.01	4.54	89.9
Pond setting 3, feed total solids 25.7 g/l					
13.6	10	36.3	9.78	5.52	76.1
	16	36.2	10.19	5.95	73.8
	32	34.4	9.27	5.66	75.2
	53	32.7	9.25	5.99	74.0

associated with the incineration of the dewatered residue. There are two major gains associated with incineration. First, disposal by landfill of the large quantities of organic residue represents a substantial cost in urban areas. The costs of hauling to acceptable landfill sites would greatly influence the economics of this system. Secondly, the installation of a waste heat boiler in the incineration system would provide more than enough steam to satisfy the process heating requirements and would improve the energy recovery efficiency, even if the excess steam energy could not marketed.



CONVEYOR SPEED - RPM
Fig. 4. Cake solids produced by a Sharpless P-600 centrifuge under various operating conditions.

A total energy balance was made for the incineration system. The basis for this balance was the energy input from the organic residue. Initial bomb calorimeter data showed a calorific value for the residue of 17 X 10^6 J/kg (7334 BTU per lb) of dry solids or 22.7 X 10^6 J/kg (9734 BTU per lb) of volatile solids. These data were for refuse from Madison, Wisconsin. Calorific values for the air classified light fraction from St. Louis are listed in Table 4.

TABLE 4

Calorific values for St. Louis refuse and residue

	Volatile solids (%)	J / kg total solids	J / kg volatile solids
Air classifier light fraction	66.4	14 X 10^6	21.6 X 10^6
Digester residue	77.1	18.5 X 10^6	24 X 10^6

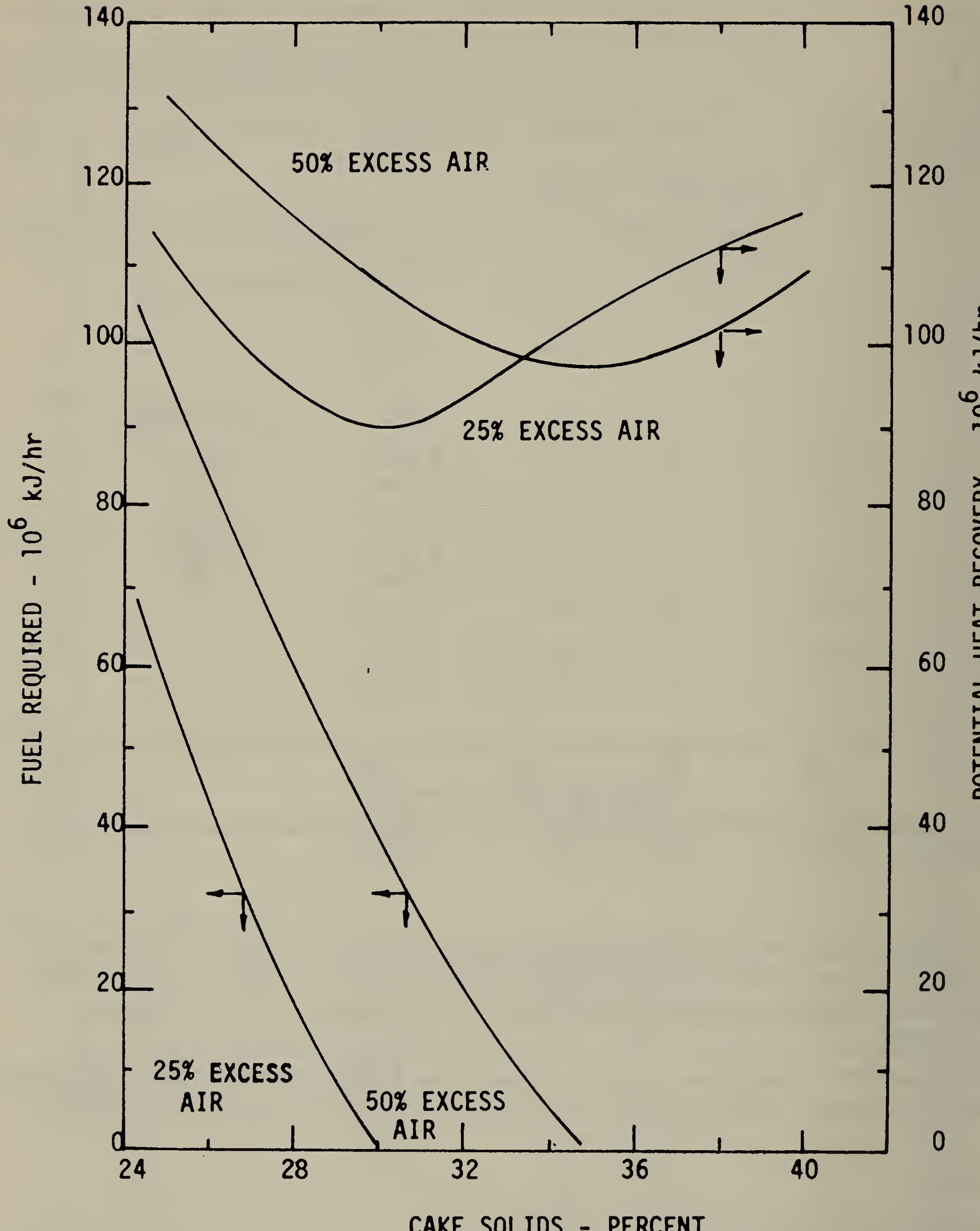


Fig. 5. Auxiliary fuel requirements and heat recovery potential for incineration of the digester residue.

The digester residue has the higher energy value in terms of both total dry solids and volatile solids. This is expected since cellulose is the primary material being fermented. Lignin, which is relatively non-biodegradable, has a higher energy value than cellulose. Therefore, the higher lignin content in the residue will cause an increase in the heating value.

An equal, if not more important, factor in this increased energy value is the higher proportion of plastics in the residue than in the raw refuse, since plastics do not degrade in the fermentation process. With as much as one-half of the organic material being converted to gas, the plastic content in the residue would be nearly twice the raw refuse content. Plastics have a very high calorific value.

Based on a carbon, hydrogen and oxygen balance, the chemical composition of the residue was estimated from measured compositions of raw refuse. This composition was used to calculate the theoretical air requirements at 9.76 kg of air per kg of volatile solids. By performing a heat balance on the incinerator, Fig. 5 was constructed. This figure shows the auxiliary fuel requirements and potential heat recovery for incineration of cake with various moisture contents. With 50 percent excess air and a furnace temperature of 760°C (1400°F), the cake solids must be about 35 percent for combustion to be self-sustaining. Reducing the excess air to 25 percent reduces the required cake solids to about 30 percent. Cake solids below these values will require auxiliary fuel.

Heat recovery from the incineration of the residue is desirable. The process heat required for maintaining the digestion temperature and for mono-ethanol amine (MEA) regeneration from the carbon dioxide scrubber is significant. The potential heat recovery in cooling the stack gas from 760°C to 315°C (1400°F to 600°F) is shown in the upper curves in Fig. 5. At a cake solids content of 30 percent and 25 percent excess air, approximately 90×10^9 J/hr (85×10^6 BTU/hr) can be recovered from a 908 metric ton (1000 ton) per day plant with the digestion system operating at 60°C and a 10-day retention time.

Additional heat can be recovered if the stack gases are cooled to a lower temperature. The installation of an appropriate preheater or economizer could recover an additional 26 to 32×10^9 J/hr (25 to 30×10^6 BTU/hr) by cooling these gases to 150°C (300°F). The availability of a market for this steam will determine how efficient the recovery system should be.

TREATMENT OF FILTRATE—CENTRATE

The liquid generated from the residue dewatering process is of very poor quality: dissolved solids range from 4 to 5 g/l, increasing with increasing recycle of this liquid to the fermentation system; suspended solids range from 4 to 6 g/l or higher, depending upon the dewatering process (see Table 5). A number of processes have been screened as candidate systems for treating this liquid. The only process that appears to have potential for reducing the pollution potential of this stream is chemical coagulation. The results of preliminary jar tests showed that iron salts can coagulate the fine solids and produce a supernatant that is low in suspended solids.

A series of tests was conducted to evaluate the use of ferric sulfate with and without organic polymers (Nalco 73C32) as coagulants for this liquid. When ferric sulfate only was used as a coagulant for the liquid prior to initiating centrate recycle, the data listed in Table 6 were obtained. A standard jar test procedure was employed in these tests. The pH was adjusted to the values shown in the table prior to coagulant addition. At reduced pH levels, lower iron dosages were required to achieve a substantial reduction in COD and suspended solids. Since ferric ion reacts with hydroxide, the higher iron requirements at the higher pH levels were probably required to reduce the pH to an optimum level.

TABLE 5

Filtrate-centrate characteristics

	Recycle ratio	
	0	0.5
Total solids	8350 mg/l	10507 mg/l
Suspended solids	4600 mg/l	5930 mg/l
Volatile solids	4340 mg/l	6093 mg/l
COD	7057 mg/l	

TABLE 6

Filtrate coagulation with ferric sulfate

Filtrate tot. solids (g/l)	pH	$Fe_2(SO_4)_3 \times H_2O$ dose (g/l)	Supernatant (g/l)			
			Tot. solids	Dis. solids	Sus. solids	COD
10.795	6.0	1.5	5.482	5.015	0.467	2.34
		1.6	5.059	5.058	0.001	1.10
		1.7	5.058	5.008	0.050	1.22
9.275	6.5	2.1	5.713	4.840	0.873	3.40
		2.2	4.800	4.732	0.068	1.345
		2.3	5.640	5.547	0.093	1.750
9.329	7.0	2.6	5.058	4.654	0.404	2.45
		2.7	4.848	4.850	0.008	1.153
		2.8	5.180	4.740	0.440	2.394

Additional studies were conducted on the centrate from the 400 liter reactor operating with a 50 percent recycle. These data (see Table 7) show that the pH had a very pronounced effect on the clarification efficiency of the coagulant. The pH shown in this table is the adjusted pH after coagulant addition. A final pH of 4.2 provided very good suspended solids removal even with ferric sulfate dosages as low as 0.9 g/l. At the higher chemical dosage, the supernatant was very clear at the lower pH. However, high dosages of iron and polymer did not achieve a clear supernatant at a pH of 6.2.

TABLE 7

Effect of pH and chemical dose on clarification

$Fe_2(SO_4)_3 \times H_2O$ (g/l)	Polymer (mg/l)	Final pH	Suspended solids (mg/l)		
			Centrate	Centrate and chem.	Supernatant
1.5	100	6.2	4930	6693	102
1.5	100	4.5	5581	6087	17
1.5	50	4.5	5581	5844	16
1.2	100	6.2	4930	6240	135
0.9	100	4.5	6776	7620	50
0.9	50	4.5	6776	7640	50

These data also show that the polymer dosage was of little significance in the efficiency of solids removal. The results were not affected at either the 50 or 100 mg/l dosage. The polymer was more important in determining the character of the sludge produced. Not only clarification efficiency, but also the settling velocity and final volume of the resulting sludge are important.

The settling characteristics of the resulting sludges were evaluated using small laboratory settling columns. These columns were one-liter graduated cylinders fitted with a stirrer mechanism operating at a speed of approximately 2 rpm. These data are shown in Table 8 for various coagulant dosages and at a pH of 6.2 and 4.5. C_0 is the initial concentration of suspended solids in the coagulated centrate; and C_u is the suspended solids concentration obtained in the sludge after 3 hours of settling. Iron dosages of 1.5 g/l and polymer dosages of 100 mg/l gave the highest settling velocity (V_s) and highest sludge solids concentration. The pH was highly significant with this coagulant dose. A pH of 4.5 produced a reasonable settling velocity and sludge concentration.

Because of the small settling columns, caution must be exercised in extrapolating these data to large-scale systems. One can expect the sludge to settle but at a rather low velocity. Consideration should be given to an alternate

TABLE 8

Settling characteristics of centrate sludges

Iron (g/l)	Polymer (mg/l)	pH	C_0 (g/l)	V_s (cm/sec)	C_u (g/l)
1.5	100	6.2	6.24	2.8×10^{-3}	12.0
1.2	100	6.2	6.69	2.8×10^{-3}	12.0
0.9	50	4.5	7.64	1.1×10^{-3}	9.8
0.9	100	4.5	7.62	1.15×10^{-3}	11.0
1.5	50	4.5	6.09	1.70×10^{-3}	9.1
1.5	100	4.5	5.84	7.7×10^{-3}	15.8

dewatering system such as a centrifuge. The large volume occupied by the settled sludge will require treatment of approximately twice the volume of water needed for blowdown. This will substantially increase both capital and operating costs for treatment of this water. Based on observations of the ability of a solid bowl basket centrifuge to concentrate these solids, it is probable that a solids concentration of 10 percent could be obtained. This concentration would greatly reduce the volume of water to be treated for blowdown purposes. Data have not been obtained to substantiate this observation, but the prospect appears promising.

The use of a centrifuge also has significance in dewatering the resulting sludge. The specific resistance of the settled sludge was measured to determine its dewatering characteristics. The specific resistance, *r*, was found to be 5.66×10^9 sec^2/g for the highest coagulant dose at a pH of 4.5. For the lowest coagulant dose, *r* was 1.65×10^{10} sec^2/g. These are both very high specific resistance values. Low filter yields would be obtained if a vacuum filter were used for dewatering of this sludge. The low volume of water — 0.378 m^3/min (100 gpm) — expected to be processed suggests that it would be more practical to take the flocculated slurry directly to a solid bowl centrifuge for both clarification and dewatering of the sludge.

COMPUTER ECONOMIC STUDY

In order to explore the economic implications of the process, a computer simulation was constructed. This program permitted investigation of the effects of changes in operating parameters and system designs on the overall process. The process flow sheet shown in Fig. 6 is one of the systems that was simulated.

The program consists of individual subroutines for each unit process from receipt of raw refuse to disposal of the dewatered residue. Each subroutine receives information from the preceding routines on the quantity and quality of the material entering the simulated process. Empirical design and cost relationships are used to determine design parameters for the process and to calculate mass, energy, and cost balances. The subroutines are designed to be independent of one another so that alternate unit process steps may be interchanged. For example, subroutines for dewatering by centrifugation and vacuum filtration are interchangeable in the program.

The capital cost routine for the simulator is not complete. It includes only the installed costs for the various processes. Such items as land, site preparation, engineering, legal, fiscal, interest during construction etc. have not been included. The data presented are for the purpose of comparing alternate schemes for the process and do not represent total costs. Therefore, these data must be used accordingly.

Table 9 shows selected results from runs of the entire process with incineration of the cake and landfilling of the ash and heavy fraction. This system was sized for 908 metric tons (1000 tons) per day of refuse. Run 1

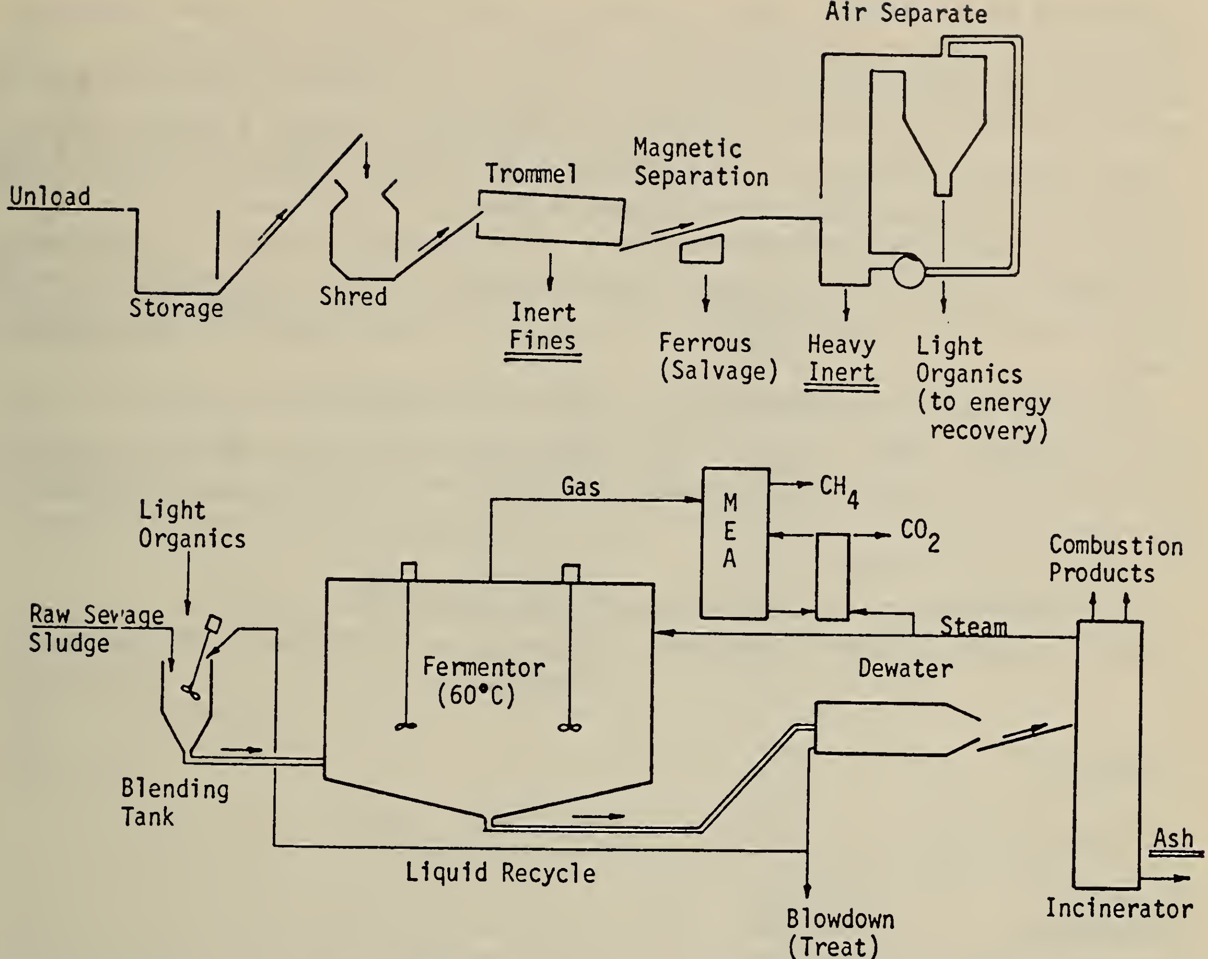


Fig. 6. Schematic of proposed system.

TABLE 9

Results of simulation

Run number	1	2	3	4	5
Digester temp. (°C)	60	60	60	50	40
Detention time (days)	6	8	6	8	8
Digester feed conc. (%)	10	10	15	10	10
Digester volume (1000 m^3)	30.3	40.4	20.0	20.1	40.4
Centrifuges req'd (No.)	9	9	9	10	11
Digester costs ($/hr)	71.90	80.90	64.70	81.41	81.77
Centrifuge costs ($/hr)	48.50	48.50	48.50	53.95	59.39
Incinerator cost ($/hr)	63.35	61.92	63.64	67.99	72.28
Methane (m^3/hr)	3905	4045	3877	3424	3000
Construction costs ($1,000,000)	14.29	14.90	13.56	15.61	16.18
Capital costs ($/hr)	185.50	190.87	179.02	199.73	207.03
Σ costs ($/hr)	405.67	412.60	398.75	425.26	425.35
Net income ($/hr)	215.33	213.40	221.25	178.74	153.65

serves as a base run; the other runs demonstrate the effect on the process of variations in design parameters. Run 2 shows the relative insensitivity of the process to digester retention time. The higher construction cost for the digester is offset by a lower incinerator construction cost and a higher gas income. Capital is assumed to be available at 6 percent; a higher interest would slightly increase the cost of the system in Run 2. Using these cost relationships, the cost of gas at higher retention times needed to have a net income equivalent to the 6-day retention time would be \$3.58 and \$3.67 per 100 m^3 (\$1.014 and \$1.04 per 1000 scf) at 8-day and 10-day retention times, respectively.

Run 3 shows a substantial savings due to a much lower construction cost for the digester when a higher feed-solids concentration is employed. Runs 4 and 5 show added costs associated with the lower temperature of digestion due to an increase in the cost of residue dewatering and incineration. Also, the gas income is lower.

The system shown in Figure 6 can be priced for 908 metric tons per day (1000 ton/day). The construction costs are shown in Table 10. These cost

TABLE 10

Construction costs

Shredder[a]	1,375,000
Separation[a]	592,000
Storage[a]	950,000
Fermentation[b]	2,230,000
Centrifuge[c]	2,050,000
Incineration[b]	5,060,000
Gas purification[a]	2,032,000
Total	14,289,000

[a] Cost data from Wise et al. (1974) [5].
[b] Cost data from Patterson and Banker (1971) [6].
[c] Cost data from manufacturer [7].

data have been adjusted to July 1973. This analysis shows that approximately 65 percent of the construction cost is associated with the fermentation and residue disposal processes. The centrifuge system and incineration accounts for 50 percent of the construction costs.

The economic justification for this added investment is shown in Table 11. Residue disposal by sanitary landfill after vacuum filtration has a low capital requirement. However, with a haul and disposal cost of \$3.30/metric ton (\$3.00/ton) of wet cake, an operating cost of \$153.72/hr is added to this system, giving a total dewatering and disposal cost of \$192.18/hr. Substitution of the centrifuge for vacuum filtration adds a higher capital and operating

TABLE 11

Residue disposal versus costs

Temp. 60°C, feed solids 10%, 90% volatile, time 6 days

		Construction	Total cost ($/hr)
Vacuum filter		1,315,000	23.01
Cake (25% solids)		—	153.72
Inorganics		—	15.45
	Total	1,315,000	192.18
Centrifuge		2,048,000	48.50
Cake (35% solids)		—	109.67
Inorganics		—	15.45
	Total	2,048,000	173.62
Centrifuge		2,048,000	48.50
Incineration		5,058,000	63.35
Credit for process heat		—	–36.01
Ash		—	3.00
Inorganics		—	15.45
	Total	7,106,000	94.29

costs for dewatering. The cost savings in residue disposal due to a drier cake compensates for this higher dewatering cost. The total residue dewatering and disposal cost is only $173.62/hr. This system will probably still cost less than the vacuum filtration system when the total capital requirements are considered.

Incineration of centrifuge cake with landfill of the ash yields a total cost for residue dewatering and disposal of only $94.29/hr. In addition to a very substantial cost reduction in haul and landfill costs, recovery of heat for heating of the digesters and regeneration of MEA gives a credit of $36.01/hr. Even with a greatly increased capital cost, this system has a much lower cost than either of the two previously discussed systems. Of course, haul and disposal costs greater than $3.30/metric ton will only increase the cost reduction due to incineration.

A detailed analysis of the costs for the base run is shown in Table 12. The shredding and separation processes have a relatively low construction cost. The shredder has a high power and maintenance cost. The cost of shredding, separation and storage, exclusive of operating labor, is $92.26/hr or $2.43/ metric ton ($2.21/ton) of refuse processed. The fermentation process has a significant construction cost plus a high cost for heating and chemicals. The chemical cost results from the large quantities of nutrients required. With nitrogen priced at $330/metric ton, this cost becomes significant. If adequate sewage sludge were available, the nitrogen in this sludge could be used to reduce the nutrient cost.

TABLE 12

Cost analysis (37.9 metric tons/hr)

	Const. cost ($/hr)	Operating cost ($/hr)			Maint. cost ($/hr)	Total ($/hr)
		Chem.	Power	Heat		
Shredder	21.72	—	14.26	—	22.13	58.11
Separation	9.31	—	3.27		3.43	16.01
Storage	14.94	—	2.10	—	1.10	18.14
Fermentation	20.17	45.96	3.19	21.38	2.58	93.28
Centrifuge	32.20	—	4.45	—	11.85	48.50
Incineration	55.16	—	—	—	8.20	63.36
Gas processing	32.00	0.30	1.55	14.63	2.35	50.83
Total	185.50	46.26	28.82	36.01	51.64	348.23

Construction cost is the major cost in the remaining processes. The centrifuge system does have a significant maintenance cost and a significant quantity of heat is required for the regeneration of the MEA. There are additional minor costs associated with the above processes that have not been identified. Table 12 includes only the major cost items.

The efficiency of energy recovery is dependent upon the type of system employed. An energy balance is presented in Table 13. The recovery efficiency in a system solely producing methane is only 32.6 percent. Because of the large amount of organic material remaining, a significant increase in efficiency can be obtained by incinerating the organic residues. If a market for this

TABLE 13

System energy balance (10^9 J/hr)

Energy available	378.3
Refuse	358.3
Sludge	20.0
Energy consumed	70.0
Power (2780 HP, 30% Eff.)	25.0
Heat (85% Eff.)	45.0
Total energy input	448.3
Energy produced	284.1
Methane	146.3
Heat (incineration)	137.8
Recovery efficiency	
Methane only	32.6%
Actual	42.7%
Potential	63.4%

steam could be obtained, 63.4 percent of the energy input possibly could be recovered. There is a use for part of the recovered steam in the process. By using incinerator heat for the process requirements, 42.7 percent of the input energy can be recovered in the form of methane.

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Resource Recovery and Conservation, 1 (1976) 315

Short communication

GOODYEAR TIRE-FIRED BOILER*

E.R. MOATS

The Goodyear Tire & Rubber Co., Akron, Ohio 44316 (U.S.A.)

(Received 19th March 1975)

Recognizing the potential energy source of the 165-million tires discarded annually in the United States, The Goodyear Tire & Rubber Company is testing a method of heat generating from whole tire combustion in a tire-fired boiler at its Jackson, Michigan, tire plant.

This furnace, originally designed by Lucas American Recyclers, was chosen after an investigation of tire-fired boiler equipment suppliers by Goodyear's Corporate Engineering Department in 1971. The basic furnace design was developed by Lucas Furnace Development, Ltd., of England with the engineering design and construction being rendered by Lucas American Recyclers and Fluor Utah. The design included a furnace with the design capability of burning 32.7 metric tons (36 tons) of scrap tires per day and a boiler to generate 11,338 kg (25,000 pounds) of steam at 1.7×10^6 Pa (250 psi) per hour. Stack gas cleaning equipment was incorporated as a contingency to reduce particulate and SO_2 emissions (though tires contain less than one percent sulfur) to comply with possible air pollution standards.

The furnace operates continually without supplementary fuel at a temperature high enough (1093°C at the center) to melt all the non-combustible material such as bead wire and fiber glass. It utilizes a rotary hearth which is sloped to a central ash discharge port. This hearth is refractory lined and water cooled around the center to protect its metallic body from the high temperatures developed inside the furnace.

Gases rise in a vortex that causes smoke and odor molecules to be consumed. An inert ash is all that remains after the whole tires complete the burning cycle.

Tires are fed onto the hearth from a vestibule by means of a pusher ram. Tires enter the vestibule through a door which closes as the furnace door opens to receive the tires. The hearth can revolve at rates of from 1/4 to 8-1/2 revolutions per hour with its rate set manually so that the tires are completely consumed in two revolutions. (In normal burning, hearth rates are in the range of 2.7 to 6.0 revolutions per hour.)

The tire-fired boiler thus meets the needs of the American society today; it generates cheap steam at no drain on fossil fuel sources while contributing a viable solution to the disposition of a troublesome solid waste component.

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*Paper presented at the Symposium "Energy Recovery from Solid Waste", March 13—14, 1975.

Resource, Recovery and Conservation, 1 (1976) 316—318

Book review

Resource Recovery and Utilization. Edited by H. Alter and E. Horowitz, American Society for Testing and Materials, 1975, 200 pages, price $20.

This book is the proceedings of the National Materials Conservation Symposium and Workshop on Resource Recovery and Utilization held in April/May 1974 at the National Bureau of Standards in Gaithersburg, Md., U.S.A. The objective of the meeting was to bring together the technology and implementation of conservation, which is reflected in the content and layout of the book. This is a particularly helpful approach with the current state of the art and political attitudes.

The book is divided into five parts of approximately equal length, of which the first introduces the subject and sets the scene with U.S. trade data and reactions of a major industry to the problems and possibilities of conservation. This is followed by two interesting papers on what might be called the business aspects. These include discussions on the problems of placing contracts for recovery systems with local government and providing the necessary financing.

The third part reviews the technology currently available for solid waste recovery. Included here are descriptions of demonstration systems in current operation or planned; a more detailed examination of one system; and a discussion of the range of unit operations available for recovering non-ferrous metals. Five significant materials are singled out for more in-depth study in the fourth part which considers ferrous metals, aluminium to represent non-ferrous metals, glass, plastics and paper. All are examined from the positive approach of practical recovery and provide useful up to date information. These are followed by reports from workshops on each of these five materials recovery areas. While maximum benefit was no doubt obtained from those attending the sessions, the reports are very valuable in that they provide a topical and practical assessment of the situation for each materials followed by specific recommendations for encouraging and implementing recovery schemes.

The book provides an interesting and valuable picture of current technology, practice, and attitudes to conservation in the United States, although most of the content is equally valid in any industrialised area of the world. It is therefore recommended as a concise statement of current thinking on solid waste recovery.

A.V. Bridgwater
University of Aston in Birmingham

Book review

The Energy Conservation Papers. Edited by Robert H. Williams, Ballinger, Cambridge, 1975, 377 pages, price $ 17.50 cloth bound, $ 8.95 paperback.

The Energy Policy Project — a study which concluded that the "best" national energy policy was that which would encourage energy conservation used this collection of commissioned research papers, in part, as source material. The consequent occasional duplication and overlap, nonuniformity of terms and other minor evidences of independently working contributors is more than compensated by the sustained quality of presentation of widely ranging but related information — and setting it into a framework for useful application.

Two of the six contributed chapters directly address energy substitution/recovery from wastes; a third deals with energy impacts/requirements of specific pollution (waste) control strategies; and a fourth chapter on economic impacts is closely supportive. Two remaining contributed chapters discuss transportation options and impacts. These chapters are supported by 15 appendices, extensive chapter notes, and thoroughly referenced sources. A somewhat disjunctive but nevertheless valuable bibliography is included. An unfortunately inadequate index (and a table of contents occasionally omitting titles) leaves the reader rather on his own. But it is clear that this compact collection will — or ought to — soon become an often reached for and well thumbed reference, particularly suited to two purposes: to provide systems planning (but not actual design) information; and as an heuristic tool for creative insight and idea production leading to waste and transportation management solutions which satisfy the complex technological and economic ramifications which underly conventionally-approached solutions. There are more than enough updates and new tabulations to motive the reader-user to throw away his carefully garnered files and folders — at least of aggregate-level data.

The chapter on metals recycling is illustrative of the general format. In this instance, three metals: iron, aluminum, and copper, are depicted as commodity flow systems; with their relationships among sectors and markets quantified. Energy demands, primary and recycled, are developed: carried back to major system components, e.g., coal mining for iron production; waste shredding. A realistic total conservation potential of about 0.4 quads can result by utilizing these metals in U.S. urban waste. The chapter on organic wastes (it includes feedlot and crop residues) which concentrates (but not exclusively) on methane production concludes with a current net energy potential of about 3.6 quads for the U.S. The chapters on transportation policy and consumer options/impacts are equally extensive, thorough, and wonderfully illuminating.

These papers may be regarded as a concise source book — not complete, to be sure — but invaluable for comprehensive systems analysis and design of waste-to-energy management programs and transportation systems.

Jerome F. Collins

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Science, Engineering, and Social Change[1]

H. Guyford Stever

Director, National Science Foundation and Science Advisor to the President, Washington, D. C. 20550

The role of the after-dinner speaker seems to be growing more difficult each year. Today's speaker is expected to address the serious issues of our time and come up with answers. At the same time, he is expected to be entertaining, and to keep in mind such things as the high cost of babysitting, and the desire of some of his audience to get home on time to catch the 11 o'clock TV news. The worst fate is to be speaking on a Monday evening, knowing that all the men in your audience are silently cursing you for each play and instant replay of Monday night football they miss.

Fortunately, this is not Monday night. Nevertheless, I'll try to take the other factors into consideration. I want to speak broadly, and briefly, on a subject that I think is of importance to us not only as members of the engineering community but also as citizens—citizens of a rather problem-filled, perplexed, and impatient world.

There are a number of reasons why it is such a world. Two of them are science and engineering, and their offspring, technology. I am not blaming science or technology for our current predicament. Others have made this a pastime and a profession by attempting to prove that science and technology have somewhat obtained a life of their own and taken us in directions we did not want to go. I do not believe this. Science and technology have given us, at each point in history, what we wanted or thought we wanted. They have been among our principal forces for social and environmental change, and will continue to be. It is only today—within recent years—that we are beginning to realize the extent to which this process, with both its good and bad effects, has been taking place, and the consequences it holds for the future. In short, we have gained an important new insight into the relationship of science and technology to social and environmental change. And this insight, as evidenced by the great surge of public interest and participation in the direction and management of technological change, indicates what may be the beginning of a new maturity and wisdom on the part of society in dealing with its future.

That technology has been a major initiator of social change can be seen everywhere in the past. This is true, for example, in the role it has played in changing the condition of women in society. Take the matter of Women's Lib. With all due respect to the present influence of the Betty Friedans, Gloria Steinems, and Germaine Greers in influencing the activities and outlooks of women today, there were others over the years whose work changed women's lives, and sometimes quite radically. Unfortunately, they were

[1] Presented at the Annual Banquet, Washington Society of Engineers, Nov. 21, 1975, National Aviation Club, Washington, D. C.

all men, with such names as Elias Howe, Alexander Graham Bell, C. L. Sholes, Gail Borden, Clarence Birdseye, and Charles Kettering. It was their innovations which changed the conditions and positions of women in society as much if not more than the social champions of their era. Take for example, the invention of Elias Howe—the sewing machine. Before this invention, four-fifths of all clothing in America was made in the home. The sewing machine moved most of that activity out of the home and into the factory, and with it, both for better and worse, came changes in the lives of millions of women.

Bell's invention of the telephone and Sholes invention of the typewriter had similar effects. They literally helped create the working girl, and the conditions that led to women's suffrage. At the same time the innovations of men like Borden in canning and later Birdseye in frozen foods changed the work of women in the home. And I mentioned Charles Kettering of General Motors because it has been said that his invention of the automatic starter put women in the driver's seat in more ways than one, and perhaps liberated women more at the time than the work of Susan B. Anthony and her suffragettes.

Just so I may give equal time to the men in this audience, let me mention that there were a number of inventions that changed the lives of men too. Many of these were what we might consider today simple innovations, yet they changed the course of history and the face of continents. One was the invention of the stirrup, which placed the knight on horseback and allowed the growth of the feudal system. Another was the invention of barbed wire, which opened the western United States to ranching and farming.

These may seem like small, inconsequential changes alongside those taking place today. Yet they are the kind of technological influences that continue to grow and have implications, both predictable and unknown, for the future. For example, no one would have considered a few years ago that today's refrigerants and aerosol propellants might pose a future threat to the environment and human health. But there is mounting evidence that this may be the case.

At the same time the continuing revolution in food processing raises some interesting questions related to our eating habits and our future nutrition. One reason for this is because two-thirds of today's meals are now eaten away from the home, and the percentage is growing. The result is that the control of our nutrition is going more into the hands of the food processing and food service industries, with many scientific and regulatory implications. (I learned this, by the way, at an NSF seminar recently conducted entirely by women nutrition experts.)

As I mentioned before, it is very significant that we have now begun to question and seek better control over the relationship between our scientific and technological changes and their effects on society. And I would like to spend the balance of my remarks on a few aspects of this situation—what it means for science and engineering, the Government, and the public.

This new awareness of the large-scale social and environmental effects of science and technology adds a substantial number of new responsibilities and difficulties to those already borne by the science and engineering communities. For those of us on the optimistic side we prefer to call them challenges and opportunities. Nevertheless, they will make great demands on us in terms of calling for more and better basic research, greater ingenuity and innovation in applying what we learn so that it can serve the best interest of society, and efforts to establish a closer working relationship with that society. This last demand must include a strong move to improve public understanding of science and technology. It must particularly convey a better knowledge of their limitations as well as their potentials, and an understanding of the costs, risks, and benefits involved in the technological and social alternatives being offered to society by science and engineering. This is an especially important matter in the kind of participatory and activist society evolving today. Unless we can improve the lines of communication and the dialogue between the expert and the citizen, we are going to be a society that is neither technologically sound nor politically satisfied—one in which we will not have the best technologies available; one of public confusion, distrust, and lack of support.

In all cases involving scientific and technological knowledge and innovations the public has a right to know—and should know—what these are, how they work, and how they can affect its future. There are a great many ways that this is being done today, particularly through public hearings involving environmental matters such as the siting of powerplants and other public engineering projects which come under Federal regulation and are subject to NEPA—the National Environmental Policy Act. Most of you are quite familiar with this so I won't go into detail on it. The National Science Foundation, however, is now expanding on this concept of involving the public in scientific and technological affairs through new programs we are considering in our Science Education Directorate. One of these—called Science and the Citizen—will seek to bring the experts and the average citizen closer together. It will support a program that will allow scientists and engineers on university faculties, and their graduate and undergraduate students, to meet with citizens' groups to discuss and advise them on matters of public decisions involving complex scientific and technical knowledge. Beginning the first of next month, we are going to hold a series of regional meetings in seven major cities to get the public's reaction and input to this proposed program.

On a broader scale we are supporting science education programs in our schools and universities that should lead to improved science literacy on the part of all our future citizens. We hope this will facilitate the process of making wise choices when it comes to choosing among complex technological options in the years ahead.

Up to this point I have been emphasizing the roles of the experts and the public in the discussion of technological assessment and alternatives. Let me say a few words about the Government's role. That role is critical for a number of reasons. One of these is that the Federal Government supports about 60% of the Nation's research and development, and particularly the R & D which determines long-term trends in technology. This, of course, does not preempt private industry from research that will lead to important breakthroughs, but it does make it more likely that industry will get much of its impetus for innovation through Federally supported work. We are, therefore, concentrating a great deal of effort these days on making the research results that come out of this work available to industry and to State and local government. This effort goes under the name of "resource utilization"—the resource being chiefly knowledge—which is going to have an increasing influence on how well we use all our material and energy resources in the years ahead.

Another way that the Federal Government influences the flow of the best research and technologies into public use is through its regulatory powers, and through the incentives and disincentives it can create through legislation, taxes, subsidies, and so forth. We are very interested in and concerned about this matter today, and trying to come up with more and better ways to get new and advanced ideas into public use so that they can be accepted and take hold economically. This includes such concepts as the solar heating of buildings.

As I'm sure you know, Federal agencies and the Congress are strongly involved in the matter of technology assessment—examining the possible long-range environmental and social effects of proposed technologies and new technological and social systems. The Congress has its new Office of Technology Assessment, and we at NSF have an Office of Exploratory Research and Systems Analysis (ERSA), responsible for supporting research in this field. Technology assessment is a relatively new field and is considered by many at this point to be as much an art as a science. With this in mind, and interested in finding out what people in Government, the universities, industry, and various professions thought about the matter, NSF a few years ago sponsored an extensive survey, part of which was devoted to finding out what subjects these people thought would be important candidates for an assessment. More than 600 experts were polled and they came up with some 188 technologies. The list holds a great variety of concepts, some quite possible to implement today or in a few years, others requiring probably years of work before they could be adopted. And they deal with social as well as technological concepts. Here are a few examples from that list:

- Fabricated foods using soy and other protein bases properly textured and flavored.
- Bacterial and viral substitutes for chemical pesticides.
- Electrical power generation using nuclear breeder reactors.
- Government data bank recording social security, tax, medical, military service, criminal, educational, and other information on nearly everyone.
- Automated hog farming.
- Sperm and ova banks.
- A national population dispersion policy leading to the creation of new towns.
- Chromosome typing for abnormalities in humans within weeks of conception.
- Accredited TV colleges and universities.
- High speed trains (200 miles per hour) connecting large cities.
- Limited weather control.
- Alimony insurance.

Those are a small number—a rather random sampling—of the 188 technologies suggested for assessment. I chose those particular examples because they include some ideas that are essentially here and in use today, others possible soon and already being debated, and a few that are still only remote possibilities. For example, we already see in our supermarkets a few food items fabricated from protein bases that have been accepted by the consumer. But this is on a very small scale. If this were to be developed extensively, and we as a nation began to switch largely to soybean and alfalfa-based foods in place of meats for our protein, the changes in our agricultural economy as well as those of other nations could be very significant. Such changes would have their effect on our land and water management, our energy use, employment, and many other situations. And we don't know how strong these effects would be.

In the case of the adoption of the breeder reactor, there is already a national assessment taking place on several levels—within the Government and by public interest groups—with the outcome perhaps several years off.

We have seen a few small examples of population dispersion to new towns such as Reston and Columbia. But what would happen if a national decision was made to do this on a very large scale throughout the country?

We know the dangers of using chemical pesticides, but also their advantages. What would a shift to bacterial and viral pesticides mean? How would it affect agricultural productivity? What would its long-range implications be for wildlife and human health?

And as far as tampering with human conception, genes or even matters related to marriage and divorce, these also have complex and far-reaching consequences, many of which are already being debated.

I have intentionally mixed technical and social innovations in my list because I think we are going to find them increasingly overlapping in their activities and influences. Hence, we are going to find assessment a field growing in its interdisciplinary aspects and in the need for people of widely different interests and disciplines to cooperate closely. This means that, perhaps, physicists and psychologists, seismologists and social scientists, and even engineers and entomologists may find themselves working together in ways they never imagined.

Of course, there will be a great number of us in science and engineering who will not be involved in this way, but will remain concerned primarily with advancing our own fields, broadening the base of knowledge, refining existing technologies, and innovating in familiar areas. In this way we will be laying the groundwork for our incremental progress and the development of alternatives to those new ideas which go through the mill of assessment and are found wanting.

Now that we are so acutely aware of the possible environmental and social implications of our new technologies we will need more than ever enough alternatives and new ideas to be flexible and avoid the crises that come from depending too heavily on any one breakthrough or purported panacea. I think we are slowly beginning to see that we live in a world where the only permanent thing is change, and where even conditions of stability are dynamic. This does not mean we cannot pursue a utopian vision or hold on to and live by long-cherished values. It does mean we have to grow in our knowledge and understanding, and in our science and technology, to control and direct the changes they can bring. If we do this it is possible to build a society and a world that, if not perfect, is at least free from many of the problems and fears we face today. And that, I believe, is a very worthwhile—and obtainable—goal.

The Role of Research in Agriculture[1]

J. Phil Campbell

Under Secretary of Agriculture, Washington, D. C. (retired).

Of all the modern miracles fashioned and achieved by man—from television to atomic energy and space exploration—none has proved more beneficial to mankind than American agriculture. Yet, fortunately for the world, the dimensions of its future have not yet been discovered. Granted, we have been blessed with hundreds of millions of acres of fertile land in the United States and a climate ideally suited to continuing bountiful agricultural production. Still, there are other countries which have not yet begun to match our agricultural production, even though they, too, possess quantities of arable land.

There are good reasons American agriculture leads the world.

First, we inherited and nurture a politico-economic system that encourages farmers to produce. No other political system has ever provided so well for a nation as the continuing American Experiment. At the same time, no other economic system can coax so much efficient productivity from the farmer and his coworkers in the food chain as

[1] Presented at a joint meeting of the Washington Academy of Sciences and the Helminthological Society of Washington, November 20, 1975, Cosmos Club, Washington, D.C.

America's capitalistic free enterprise system.

Secondly, our American agricultural miracle springs from a unique system of scientific discovery and information dissemination that invariably meets and usually surpasses the needs of its time. It is a system that is supported by the American people through all levels of their government, as well as through private enterprise, the scientific community, the educational system and the farmer themselves.

Our winning combination is incomparable. Yet we want to share the production that flows from our labor and genius as well as the know-how that produced our success. Practical as well as generous, Americans know they cannot feed all the world today, much less the world of tomorrow, and that the more nations which benefit from adoption of our successful methods, the better.

Millions in the underdeveloped world need the kind of productivity that science and the farmer have achieved in America. Consider:

- The time required to produce 100 bushels of corn in America has dropped from 135 hours to just 6 hours in 60 years.
- The number of man-hours required to produce 100 bushels of wheat dropped from 106 to 9 in the same period.
- In 1970-74, it took somewhat less than 1 American man-hour to produce 100 lbs. of turkey. In 1910-14, it took nearly 4 working days (31.4 man-hours).
- One hour's farm labor now produces nearly 9 times more than it did in 1921.
- In 50 years, U. S. crop productivity per acre has more than doubled.
- The average farm worker in the United States today supplies food and fiber for 52 persons. Just 10 years ago he was producing enough for 29. By comparison, a farm worker in the Soviet Union today produces enough for only 8 persons, while a farm worker in France produces enough for only 14.
- While an estimated one-third of the work force in the Soviet Union is engaged in agriculture, only 5% of the work force in America is employed on farms. The other 95% is free to produce such consumer goods as refrigerators and automobiles, and to provide such needed services as medical care.
- There were 2½ times as many farmers in America in 1950 as there are today, yet agricultural output in this country last year was twice what it was 20 years ago. Obviously, we must be doing something right.

Frankly, it is time the world recognizes and applauds those scientists—past and present—who have painstakingly persevered throughout the years to provide our farmers with the keys that unlocked such productivity.

Consider, for instance, the men and women through the years who made it possible for the United States to produce half of the world's corn in today's market. The development of hybrid corn and its utilization in the United States has become a classic example of the teamwork between scientist and farmer which made the American agricultural miracle possible. In the 1930s, 22 bushels per acre was the average corn yield in the United States. Today, the average is about 95 bushels per acre. In 1973, one farmer actually produced 306 bushels per acre. And we're still working with corn, changing its color, its growing habits and its nutritional content.

The number of our successes is virtually endless, and the range is equally impressive. Not only do we breed leaner hogs to meet changing consumer preferences, but we feed them better and keep them healthier. Scientists and farmers and those who help them have practically eliminated hog cholera and cattle brucellosis, two deadly livestock killers, in this country.

It is the genius of man which stands out when we look closely at the miracle of

American agriculture. The golden soybean, said to be the world's most effective producer of protein per acre, has a history in the Orient that goes back more than 3,000 years, yet it achieved its present great stature as a hunger fighter in the United States. Even the chicken is not a native American bird, but a jungle fowl of India and the Far East, brought to this country by the first European settlers. Which nation coverted the Sunday special dinner into an everyday feast at the dinner tables of millions of people? You guessed it. America.

The economic benefits of such scientific progress are immeasurable. Marek's disease in poultry, for instance, was costing the United States more than $200 million a year until an effective vaccine was developed. Now losses have been cut by more than 70%. Sometimes our successes sound like the alchemy of changing lead into gold. Scientists in my native state of Georgia, for example, converted one of nature's peskiest grasses, common bermudagrass, into an outstanding forage plant by cross-breeding it with grasses from South Africa.

I could go on and on. Each of you could think of a dozen great scientific breakthroughs in agriculture that I have not mentioned, discoveries that helped change the course of history at least to some extent. We who are close to American agriculture know the value of our scientific accomplishments and it is only human if we should wish that our work be more appreciated. Beyond a doubt, the delicately balanced forces of our world are more stable today because American agriculture is producing enough to export $20 billion worth of urgently needed farm products in the world markets. That alone should generate appreciation from the predominantly nonfarm-oriented segment of our society. I can't help wondering if the same stabilizing effect would result if some other country were supplying these needs.

Still, we do not seek appreciation so that we may hear praise. We seek it, rather, so that when Americans assess the role that they must play in solving the problems of tomorrow, they will realize the full worth of the tools they already possess. Certainly, the miracle of American agriculture is among America's and the world's most potent implements for good.

We in America cannot begin to absorb the full productivity of our agriculture. American farmers now are setting production records in nearly every major crop almost routinely. Yet consumers in the United States, on an annual basis, use only 40% of the wheat, less than half the rice, one-half the soybeans, 60% of the tobacco, two-thirds of the cotton and three-fourths of the corn the American farmers produce. Our successful agricultural system demands markets beyond our borders. That part of our production which is not used at home is exported for cash to meet the needs of customers abroad, rather than being stored as surplus, which was the unfortunate disposition of much of our production in years past. Today, the markets are there and I am convinced they will expand, with fluctuations, in the years ahead.

American agriculture is a miracle today because the scientists and farmers of yesterday found the answers to yesterday's problems and more. There was a time, in the early years of this nation, when "going west" solved the problem of infertile soil. When the white man first came to this land of promise, he cleared land and worked it until he had drained it of its nutrients. As productivity declined, he moved on. Then he cleared more land or plowed up the native grass and started farming in his new location. Americans repeated this process until finally there were no new lands left to settle. Yields per acre sank lower and lower as fertility declined. As they faced an ever-growing population, Americans saw their geographical frontiers suddenly restricted by two oceans and the borders of Mexico and Canada.

They turned to the new frontiers of increased production. With the introduction of the cotton gin, cotton production in the South soared from 10,500 bales in 1793 to 4½ million bales in 1861. Steel and polished iron plowshares were developed to open the heavy, sticky soils of the prairie. The mechanical grain reaper multiplied the harvests. A revolution was underway on American farms in the 1800s, just decades after the political revolution freed us as a Nation to pursue our own destiny. It was the beginning of the modern miracle of American agriculture.

In their wisdom, our leaders in 1862 created the U. S. Department of Agriculture, "the general designs and duties of which shall be to acquire and to diffuse among the people of the United States useful information on subjects connected with agriculture in the most general and comprehensive sense of that word, and to procure, propagate, and distribute among the people new and valuable seeds and plants." The same year, the Congress passed the Morrill Act, which established our uniquely successful Land Grant University system. A hundred years ago this year, another significant step was taken in Connecticut—the first State Agricultural Experiment Station was opened.

At this point, nearly all of the ingredients of the miracle were in place. Later (in 1887), the Hatch Act provided for a nationwide system of State Experiment Stations, and (in 1914), the Smith-Lever Act created the Cooperative Extension Service. Both moves were immeasurably successful and key contributors to the American agricultural miracle. Then and later, farmers found they needed all the help they could get just to stay even in the face of world surpluses, depressed prices and competition. Now, a more demanding (though no less competitive) world benefits from the successes of the system we created.

From the beginning, the challenges to our system have been real. But we grew stronger, rather than weaker, as we met them. As recently as in 1970, our agricultural science community was tried and proven strong. That was the year the corn blight *Helminthosporium maydis* struck the corn crop of the United States and reduced it 20-25%. But we had a scientific team put together that could stop the blight in its tracks within a short period of time. Within 24 months we had a bountiful supply of blight resistant corn seed. The episode, however, gave us a warning. It reminded us—scientists, farmers, and government employees alike—of the danger of widespread dependence upon plants which are genetically uniform. Find a disease that can kill one such plant and you could wipe out the entire crop of a nation, we were reminded.

Our American agricultural system is the miracle of the modern world, but it is not without problems. When the scientist brings a new and shiny tool of production to the farmer, for instance, there have been times when the farmer felt he could not afford to employ it. With the scientist's previous help the farmer may have produced a record crop, but the prices he received for that production may have been discouragingly low. Fortunately, with new and expanded markets at home and abroad today, the prices of farm products have brought returns that cover the cost of modern agricultural technology. Traditionally, farmers have been limited in the use of new technology by low prices.

The American farmer has entered into a new day of well-being, with all-time highs set in net income—$29½ billion in 1973; $27.7 billion in 1974 and an estimated $25 billion this year. With this has come a great surge in crop production per acre and more efficient production of livestock and livestock products. Previously, for several years, farm income in the United States fluctuated between $11 billion and $17 billion, and $2 to $4 billion of that came out of the pockets of American taxpayers as a subsidy.

Because of today's favorable climate and an encouraging outlook for marketing in the future, most of the fruits of research available today have been adopted by farmers. It is imperative that new technology be developed for ready use when the marketplace demands it. What are some of those needs, as we see them today?

A meeting of scientists, farm leaders and interested others in Kansas City, Mo. in July indicated which direction we must take. Energy is the field which should claim our first priority in research, the conference decided. The agricultural scientist's interest in energy spans a wide area, from strip mining to photosynthesis, from reduced tillage to frozen foods. Farming uses only 2.8 percent of the total fuel consumption in the United States, but there is always room for improvement in efficiency. The science-farmer team has already made fuel savings on reduced or no-tillage operations common throughout the United States. But a further 20% reduction in tillage by 1980 could reduce fuel requirements for tractors by about 425 million gallons that year alone. Partly offsetting this, of course, might be the increased use of energy to produce more pesticides and more reduced-tillage equipment.

Strip mining could become a major problem in the northern Great Plains as the Nation strives to find substitutes for foreign-produced oil. About 45% of the Nation's coal reserves are in the Dakotas, Montana and Wyoming and the terrain invites intensive strip mining. But unlike the East, where the mine spoil material is highly acidic, a big problem in the West is the high concentration of salts in the spoil material. Research findings so far are beginning to form the basis of a technology for returning vast areas of the northern plains to productive agriculture after coal extraction. Researchers, for instance, believe that the four-wing saltbush may be a promising native browse plant economically useful for reclamation of spoil surfaces. Sheep, cattle, antelope and deer like it, too.

The second highest priority for research assigned by the Working Conference to Meet U.S. and World Food Needs was increased soybean production. Soybeans, one of our most important crops, have stubbornly resisted research efforts to increase yields. The average yield per acre was 20.1 bushels in 1955 while this year it is an estimated 28.4 bushels. Soybean research has taken many approaches to the problem already, with physiologists probing the photosynthesis route and nutritionists seeking ways to make the plant use fertilizer nitrogen more efficiently. Other researchers are seeking clues by studying the overall relationship between plant and nematodes, one of the great natural enemies of soybean production.

The third priority area for research assigned by the conference was the more efficient use of water for agricultural production. The problem is as old as agriculture itself and promises no let-up in the future. For one thing, if the coal mined in low rainfall regions of the West were to be processed there, considerable quantities of water might be required, perhaps competing with agricultural needs in some localized areas.

The conference decided the fourth priority should be assigned to research on basic problems in plant growth and production, while fifth priority should go to the determination of the nutrient requirements of people. Beyond those, a wide range of other potential research subjects were listed in descending order of priority. These weren't the decisions of scientists alone or of farmers alone or of consumers alone. Spokesmen for farmers, ranchers, food processors, consumers, marketing firms, nutritionists, farm organizations, labor unions, international development experts, environmentalists and federal and state researchers attended that conference.

The setting of priorities on such a scope shows us surely that the miracle of American agriculture continues to thrive and grow strong.

American agriculture continues to meet its challenges. Farmers can look forward to continuing good years ahead, though occasional bad years will creep in because of poor weather or low prices. More than ever, successful farmers will continue to need the fruits of research. I am confident they will get them.

Experiences of an Engineer, Who Happens To Be a Woman

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ABSTRACT

The Equal Employment Opportunity laws see to it that women can get employment in the engineering field; however, getting a job is only a small part of it. Women in engineering face several problems and challenges—some subtle, some blatant—that are discussed.

General Attitudes

"Engineers who are women" and "women engineers" are not one and the same. Therein lies the key to the biggest problem and challenge facing women in the engineering field today.

An engineer is a person who applies scientific principles to practical ends as the design, construction, and operation of efficient and economical structures, equipment, and systems to solve the problems of our time and improve our standard of living. Engineers have several traits in common, among which are: The ability to solve problems, an interest in mathematics and science, and an urge to make creative use of their intelligence. Is it necessary to mention that these traits cannot be defined as either masculine or feminine, but rather as "personine"? However, society presents these as masculine traits and discourages women from using their intelligence by expecting them to avoid responsibility, decision making, and competition, and by underrating their ability. This was expertly summed up in the February issue of the Reader's Digest in Dr. David Reuben's article, "The Marriage Game." Dr. Reuben states, "A whole mythology has been developed, through endless jokes and cartoons, about women who crumple fenders, burn dinners, can't balance the checkbook and spend all their time playing bridge with the girls. There are, unfortunately, no cartoons or jokes featuring the women who *don't* do these things, but who hold down full-time jobs, create gourmet meals and when the day is over, become provocative companions."

Thirty-three percent of Russia's engineers are women, 1% of America's engineers are women. Are American females less intelligent than Russia's, or is it due to the fact that in Russia, a woman's intelligence is accepted and utilized? It is unfortunate that this country continues placing numerous social stigmas on the intelligence of women rather than utilizing this vast intellectual potential.

When a man makes a career choice of engineering, choosing a career for which he is suited is the only thing he must resolve. However, a woman is faced with two items of concern—that of choosing a career (which in itself goes against the norm of society); and that of resolving the inner conflict of doing something that is considered masculine and consequently the fear of not being accepted in the career for which one's *abilities* are best suited. Women who are in engineering are usually of strong character, tend to be more stubborn, and are not afraid of going against the accepted norm of society.

Once a woman is in the engineering profession she may encounter some obstacles. These obstacles are a result of the attitudes—some subtle, some blatant—that have developed from the mythology about women. Engineers who are women are too often looked upon as women engineers, thus all the social stigmas are attached. Consequently, we have an intelligent person who is fully capable of solving problems, being creative and dedicated; however, she cannot be given full responsibility and a decision-making position, since she is a woman.

Let us examine some of these myths, connotations, and prejudices:

Longevity in the Work Force

Many employers feel that it's not worth the cost and investment of training, etc. for a woman since she will drop out of the work force in a short time to raise a family. Isn't that a decision to be made by the woman, not her employer? When an employer hires a man he has no guarantee as to how long he will stay there. If a woman has made it through engineering school and into the business world, chances are pretty good she's not going to give up her career too easily.

It is also said that a woman will put her family first; certainly a man should too!

Many women successfully combine career and family. An excellent example of this was Dr. Lillian Moller Gilbreth, a very prominent woman in the field of industrial engineering and management. She also happened to be the mother of twelve children—which is recounted in the book, "Cheaper By the Dozen."

Travel

Many women are denied the travel which may be necessary for their job or for their career development since it is felt they may not be able to fend for themselves. Anybody who can get through engineering school is perfectly capable of riding on an airplane, renting a car, following directions, and carrying a suitcase. Any person who can drive in the rush-hour traffic of our asphalt jungles to work every day should be just as safe attending an engineering conference in Chicago or Los Angeles.

Travel is even more frowned upon if a man from the office must also go on the trip. In this situation a woman takes with her a suitcase containing the taboos and fears of society which are amplified by the attitudes of co-workers and wives.

Influence

It is frequently stated that "women subtly influence men." The irony of this statement is that for a woman this is considered to be a bad characteristic and is detrimental; whereas if a man has this trait, it is known as leadership.

Women are having an influence on the engineering field as a whole by "softening" its image. People are beginning to realize that engineers work in decent environments and solve challenging problems rather than just tramping around at construction sites in hip boots and hard hats.

Management

It is usually stated that women can't be promoted to management since men won't work for women. This goes back to society's stigma of men being superior and women inferior. People work for people and engineers work for engineers. To be a manager one must be competent in the profession, have self-confidence, and be able to cooperate with others. One must also be compassionate, understanding, and tactful. These are traits which, again, can't be attributed as specifically masculine or feminine, but personine.

Personal Experiences

An agricultural engineer is an engineer who applies the principles of engineering to agricultural problems such as soil and water conservation, waste management, power and machinery, food processing, farm structures, and energy conservation.

The combination of growing up on a farm, being interested in soil conservation, and liking math and science led me to select agricultural engineering as my career. During the summers (between college terms) I gained work experience by working as a student trainee engineer with the USDA-Soil Conservation Service. I was fortunate in that they did not deprive me of field work (one of the reasons I chose agricultural engineering was to be able to work outside); however, they did ask if I wanted to do field work, whereas for a man this is taken for granted.

Being an engineer who happens to be a woman has at times had its problems. Such things as convincing the professional societies' mailing lists that it's Mrs., not Mr.; that if I am to be an officer, if I'm good enough to be a secretary, why not president?; when surveying in the field and climbing up and down gullies, pants will split; yes, I can carry my own transit; and yes, I can change a flat tire!

A frequent problem is that the people with whom I work will tend to *assume* what I want to do, rather than let me make my own decisions, especially when it comes to a choice between desk work and field work. They will assume (rather than ask) that I'd prefer to do the desk or lab work.

I worked in industry for a year and encountered a major obstacle. My manager refused to give me any challenging work or anything that may require training since he had the attitude that "women only have a career of about seven years." He also was the very protective father image and wouldn't let me stand on my own two feet, lest I fall. Needless was that *his* manager was a very competent engineer who happened to be a woman.

Fortunately, I find the engineer just out of college is more capable of comprehending working with or for an engineer who is a woman, than does a man who has been on the job for 40 years. The younger engineer is more likely to have had girls in his engineering classes and after awhile just takes it for granted that women can be engineers. For example, if a female told my husband she was an engineer he'd probably just say, "what's unusual about that?" Considering only 1% of America's engineers are women, he is in a unique position—he is married to an engineer, and in the group of six engineers with whom he works, two are women.

Personally, I think engineering is a good field for a woman. I am satisfied with the career I selected and find it challenging and rewarding. It's a career that trains a person to *think* and reason things out. This aspect of engineering is important, no matter where you are or what you do.

Conclusion

Recruiting efforts, etc. are beginning to make an impact, and girls with an interest in math and science are starting to consider engineering as a career choice. In 1975 about 820 women were obtaining engineering degrees in the U. S. and about 1,000 are anticipated for the current year.

As more women become successful in the engineering field, the stigmas should gradually ebb away. The challenges and problems faced by women in the professional fields are dynamic—they are constantly changing. The law protects women as far as employment goes—only time, patience, competence, and success will be able to fully remove the myths and "old husband's tales" that go with being a woman.

Let us stress the term *good* engineer, regardless whether man or woman.

The most important thing that can be done for women in engineering is to emphasize the fact that they are *engineers* who happen to be women, rather than emphasizing *women* engineers.

Benjamin Franklin, American Physicist[1]

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Benjamin Franklin, called the first true American, was born on January 17th (NS) 270 years ago in the seaport town of Boston, soon to become the cradle of American liberty. His father, a tallow chandler, was an emigré from England; his mother, a Folger from Nantucket. He was baptized across the street from his home in the puritanical Old South meeting house, where colonial patriots would later congregate; a pragmatic freethinker, a deist, he would be buried alongside his Anglican common-law wife, Deborah Read, in the Christ Church burial ground in Philadelphia. Despite his inability to marry his landlady's daughter, owing to the disappearance of her husband, and her desire not to accompany him on his sojourns abroad, he had a strong sense of family ties and obligations, verging on nepotism; he early acknowledged publicly his premarital illegitimate son William and included him in his household.

When eight years old he entered the one-room grammar school that later became the Boston Latin School; two years later he became its most famous dropout. Self-educated, he received at 47 an honorary M.A. from Harvard and from Yale, at 50 one from William and Mary, at 53 an honorary LL.D from St. Andrews (hence the appellation doctor) and at 56 an honorary D.C.L. from Oxford.

At twelve he was apprenticed to his brother James, who published one of the two Boston journals. Five years later he ran away from Boston, which now boasts a statue in his honor in front of its City Hall, to metropolis Philadelphia, later to become the capital of a new nation. Penniless, he entered this city, which now has a commemorative statue atop its postoffice center. He worked there and temporarily in London as a journeyman printer. At 22 he opened his own printing shop; two years later he became the official printer for the Pennsylvania Assembly. Personally ambitious, industrious, and shrewd, he was able to retire wealthy at 42 from active service. On a statue in Washington, D.C., the front bears the inscription Printer; his will began, "I, Benjamin Franklin, Printer." On the right side is inscribed Philanthropist, on the left Philosopher, and on the back Patriot. A many-sided personality, nevertheless he was an integrated person.

At 16 he wrote letters under the pseudonym of Silence Dogood for his brother's newspaper; seven years later he himself started publishing the "Pennsylvania Gazette" (later named the "Saturday Evening Post") and at 27 the annual

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[1] Based on "Benjamin Franklin: New World Physicist" by Raymond J. Seeger (Pergamon, Oxford, 1973). This paper is written to celebrate Franklin's birthday in the Bicentennial year.

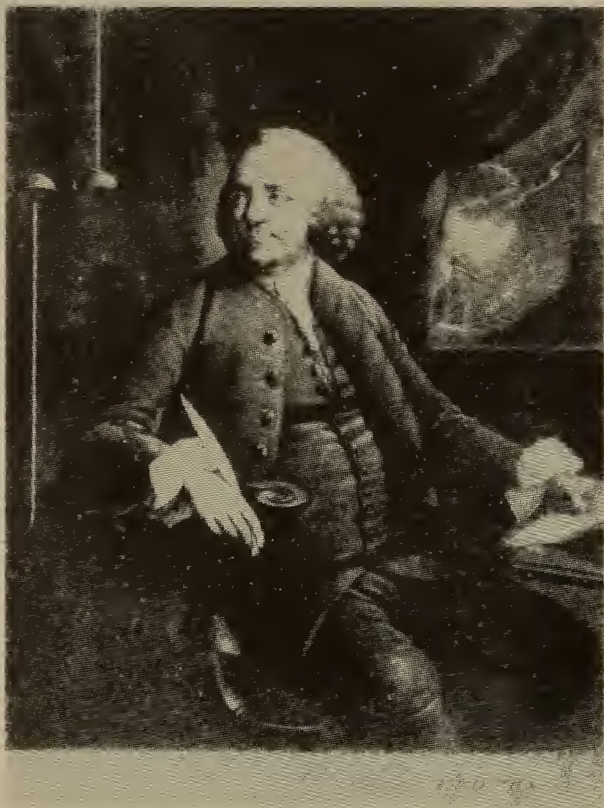

Fig. 1. Benjamin Franklin at 56 (M. Chamberlain, Metropolitan Museum of Art).

"Poor Richard: an Almanack," written by a fictitious Richard Saunders. At 65, during a week's stay at the Twyford home of his friend Jonathan Shipley, Bishop of St. Asaph, he wrote Part I of a literary classic for his son, his celebrated "Autobiography" (Part II was begun at the age of 78, Part III completed at 82, Part IV unfinished). He wrote simply about the daily concerns and intimate thoughts of the first fifty years of the life of a self-made man; it was not published until 1868. Later he was regarded as the best writer in 18th-century America; some even claim that he established the so-called style of American literature.

A city man of affairs, he was active in promoting the public welfare; he himself had a flare for organizing. He seemed to be guided by Poor Richard's apothegm of 1857. "The noblest question in the world is, 'What good may I do with it?' " With nine leather-apron companions at 21 he formed the Junto, a society for mutual improvement. To facilitate its activities he organized four years later a Library Co. (at the time of his death he had the best and largest (4,000 volumes) private library in the colonies); he himself was an avid reader. At 30 he helped to form the voluntary Union Fire Co.; in 1752 he was instrumental in organizing a Fire Insurance Co. At 31 he was appointed Philadelphia postmaster; sixteen years later he became a royal-appointed deputy postmaster general of North America and at 69 was elected the first postmaster general by Congress. At 37 he proposed a society for promoting useful knowledge, which led to the founding of the American Philosophical Society; upon its reorganization in 1769 he became the first president of this prestigious national group. At 43 he became president of the public Academy of Philadelphia (for practical education) which developed subsequently into the University of Pennsylvania. At 49 he assisted the ill-equipped forces of General Edward Braddock in procuring transportation and helped to organize defense against marauding Indians who were wont to prey upon the peace-loving Quakers and German settlers. The following year he promoted the formation of a volunteer Philadelphia militia. At 81 he was still busy with organizations—for example, he then helped form a Society for Political Enquiries and was elected president of a Society for the Abolition of Slavery. A common man, he remained a man of the people throughout his whole life; he was a true philanthropist, a lover of man and a promoter of the general welfare. No wonder he was affectionately called "the sage of Philadelphia," a modern wise man.

Franklin's industry was productive not only in his professional trade and in his social philanthropy but also in his amateur science. The generic term philosophy at that period included natural philosophy, what we nowadays call physical science. Franklin had a persistent curiosity about such natural phenomena; he had an innate desire to understand them and an ingenious ability to ferret out their secrets as well as to make use of their properties. He did not, however, have sufficient leisure to enjoy performing experiments until he retired at 41, when he became inquisitive about electrostatic phenomena, which were popular as fashionable demonstrations at that time. His own observations over the next four years were compiled as an English book on "Experiments and Observations on Electricity" (no American edition was published until 1941).

Up to that time only four basic facts were known about electricity; one theory had been proposed to explain them. In the first place, as early as the 6th century B.C. the attraction of amber for light materials had been recorded by Thales, one of the seven wise men of Greece. Other substances with the same property were noted through the ages; they were said to be electric, i.e., like amber (Greek electron), as distinct from non-electrics which did not exhibit such a condition when rubbed. Early in the 17th century a second fact was discovered, namely, the repulsion of light objects after making contact with an electrified body; it was observed by the Italian Jesuit Nicoló Cabeo. The French scientist Charles F. de C. du Fay inferred in 1733 that there are two electric fluids contained in each body (like water in a sponge) that would be released by friction; one resinous (like rubbed amber), the other vitreous (like rubbed glass). In the 17th century Otto von Guericke, a German physicist, was the first to note that such an electric effect could be transmitted to some degree by a linen thread. This third property, the conduction of electricity (a term introduced about 1646 by the English physician Sir Thomas Browne), was investigated by the Charterhouse pensioner Stephen Gray: conductors turned out to be the non-electrics; insulators, electrics. Electricity did behave like a fluid. One of his spectacular experiments (1730) was repeated in 1744 at Philadelphia by a lecturer, Archibald Spencer: an electric spark was drawn from the nose of a suspended boy whose feet had been rubbed with a piece of glass. The fourth fact was the possibility of storing electricity. The Dutch natural philosopher Pieter van Musschenbroek, who in 1750 advised Franklin "to study nature, not books," was shocked in 1746 when he tried to store some electric charge in a phial containing a gun barrel in water (he had grasped the gunbarrel with one hand and the phial with the other). The resulting Leyden jar (partly coated on the inside and on the outside with tin foil) became popular for demonstrating electric discharges—a glorious entertainment, as when in Paris a charge was passed through Carthusian monks, lined up hand-in-hand 900 feet. It is not surprising that at this very time Franklin became fascinated by these new electric phenomena. Fortunately, the field was uncultivated and could be made productive with simple experimental techniques (mathematics, a Franklin weakness, was not then a prerequisite). It should be borne in mind that Franklin himself was a skilled craftsman, adept at handiwork. Probably his greatest scientific contribution was his design of crucial experiments for testing hypotheses.

In 1746 the Library Co. had received a greenish glass tube for electric use from its London agent, Peter Collinson, a Quaker mercer and botanist. Franklin reported his own findings, beginning in 1747, to Collinson in letters. The very first one begins with the following experiment. Two persons each stand on a cake of wax (an insulator). The first person rubs a glass tube which causes a spark to jump (no contact) to the second. Both appear electrically charged to a third person standing nearby on the floor. If the first two persons touch each other, neither will be finally electrified. Franklin offered a simple explanation. Assume that the rubbed glass has an excess of a single electric fluid and then some of it is transferred by a spark to the second person. The net result is a deficiency of the electric fluid for the first person, an excess for the second; contact neutralizes their differences—an implicit assumption of the conservation of electric charge. The normal amount of electric fluid is an uncharged body is neutral in its electric effect. Franklin designated an excess as a positive electric charge, a

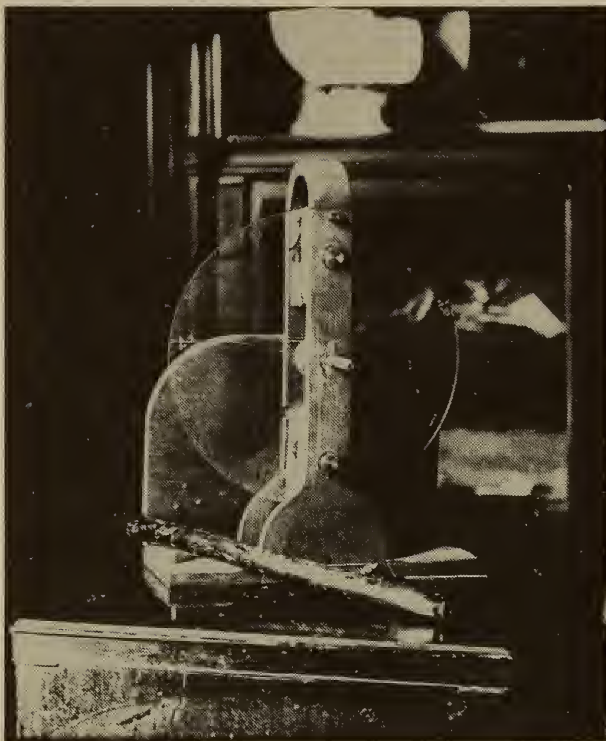

Fig. 2. Franklin electric machine (American Philosophical Society).

deficiency as a negative one. This one-fluid theory requires only electricity and matter, not two kinds of electricity and matter. An unresolved problem, however, was the apparent repulsion of matter without electric fluid (i.e., negatively charged), whereas matter *per se* exhibits only gravitational attraction. Both theories were then adequate to explain known electric phenomena—a dilemma arising from the study of the conduction of electricity in metals. A second dilemma arose later through Michael Faraday's investigation of the conduction of electricity in certain liquids. Electrolytic results could be simply explained by the supposition of atomic ionic carriers each with an integral number of positive or negative charges. Were there discrete units of electric charges or were the carriers themselves limited to integral capacities? Was electricity a continuous fluid or essentially atomic in structure? The answer to both these dilemmas was latent in the neglected field of the conduction of electricity in gases. It had to await the 1897 discovery of the negative electron by Sir Joseph J. Thomson, who regarded Franklin as "a physicist of the first rank." Both theories were partly right and partly wrong; there are two electric charges, but only one moves in a metal, the negative electrons. (The generally accepted direction of an electric current is that of the motion of the positive charge, opposite the actual motion of the electron current—linguistically confusing, but no more so than speaking of the rising and setting sun.)

Franklin found that a conductor could be given a permanent charge (opposite) by induction (no contact) and then grounding it. He was thus enabled to explain the behavior of a Leyden jar, which was found to have equal but opposite charges inside and outside, i.e., a condenser. In 1755 he observed that a cork suspended in an electrified silver can was neither attracted nor repelled by the walls (cf. Faraday's famous ice-pail experiment in 1843). Later his friend the Unitarian minister and chemist, Joseph Priestley, who came to Northumberland, Pennsylvania, in 1794, correctly inferred (1766) from this fact the existence of an inverse-square law of force between relatively small electrified bodies—the beginning of a quantitative outlook in electricity.

Undoubtedly Franklin's most spectacular scientific success was his experimental confirmation of the hitherto speculation about the relation of electric sparks to atmospheric lightning. The basis for his thinking was his recognition of the peculiar discharge by pointed conductors, called to his attention by his coworker, the lawyer Thomas Hopkinson. Franklin compared the two phenomena: in twelve respects they were similar. Accordingly he designed a critical test; in 1749 he was satisfied and wrote in his notebook, "Let the experiment be made!" Some members of the Royal Society of London laughed at his notion when it was reported by Collinson (1750). The French, however, took the idea seriously. At the suggestion of the naturalist George L. le Clerc, Comte de Buffon, the botanist Thomas F. Dalibard succeeded on May 16, 1752, in drawing electricity from a (charged) cloud during a clap of thunder by means of a 40-foot iron rod erected vertically in a Marly-la-Ville garden just outside Paris. The experiment was successfully repeated the following week in Paris by M. Delor. Meanwhile, apparently waiting for the completion of Christ Church steeple and unaware of the European work, Franklin performed a modified experiment with a kite flying on a wet string, probably with his 21-year old son on the outskirts of Philadelphia, away from any skeptical spectators. Electricity was induced by a nearby (charged) cloud on a metal point protruding from the kite; it was conducted by the string to a key attached to the end. Here Franklin was able to produce a spark when his knuckle was brought near it—obviously not a lightning bolt, otherwise he would have been killed as was the less fortunate Swedish physicist, George W. Richmann, who was struck dead in experimenting

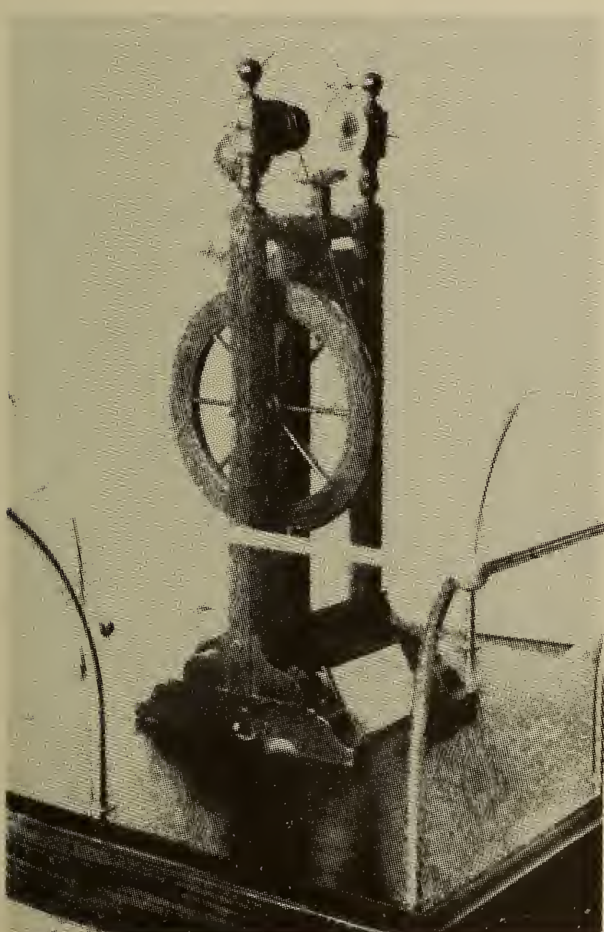

Fig. 3. Franklin electric machine (Franklin Institute of Philadelphia).

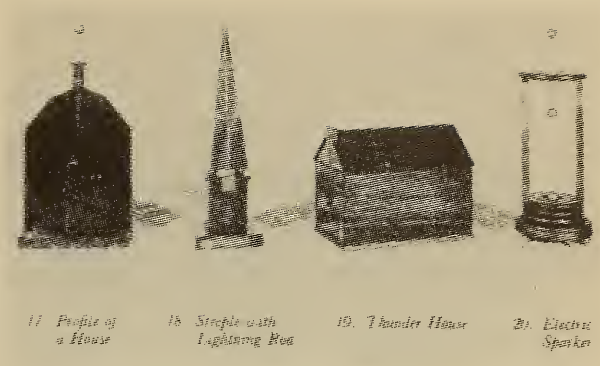

Fig. 4. Franklin spark demonstration models.

with a rod at St. Petersburg the year following. A modern Prometheus, he had truly stolen fire from the heavens. As the French finance minister and physiocrat, Anne R. J. Turgot, stated in a Latin epigram in 1776, "Eripuit coelo fulmen sceptrumque tyrannis" (he snatched lightning from the sky and the scepter from the tyrant).

A friend of the best scholars in America, he proved to be a vital link of communication between the new world and the old world. In 1753 he became the first foreigner to receive the coveted Copley medal awarded by the Royal Society for the "most important scientific discovery." Three years later he was made a Fellow of that society. In 1772 he was elected one of the eight foreign associates of the French Académie Royale des Sciences (it was 100 years before another American was so honored).

Franklin's curiosity about nature was not restricted to electrical phenomena. He was interested in the German pulse glass, in the variation of thermal absorption by differently colored fabrics, in the use of some oils to calm water waves, in the dependence of the fluid drag of a boat upon the depth of a canal. He pursued a funnel-shaped whirlwind of dust in the Maryland countryside; he associated the wind blowing from the northeast with a storm following a path from the southwest; he ascribed a constant European "dry fog" to volcanic smoke; he identified the Gulf stream by his daily measurement of ocean temperatures during his eight month-long trans-Atlantic voyages.

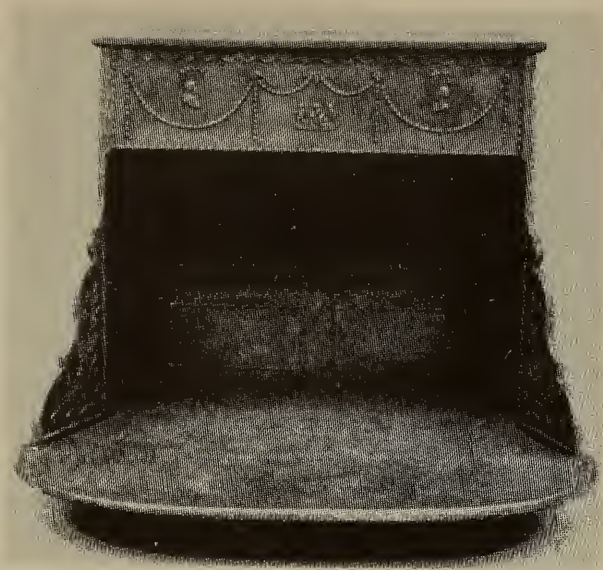

Fig. 5. Franklin stove (1795 model—Metropolitan Museum of Art).

Franklin is more commonly remembered for his practical interests and utilitarian concerns epitomized in his 1761 comment to his London landlady's daughter, Mary Stevenson—"What signifies philosophy that does not apply to some use?"—and in his sententious retort to a disparaging remark about the Montgolfier brothers' hot-air balloon flights—"What is the use of a new-born baby?" We recall his many inventions, his household gadgets: a flexible catheter for his ailing brother, bifocal spectacles for himself, a mahogany armchair convertible into a ladder, a "long arm" for reaching books on high shelves, a closed cast-iron stove in lieu of the open-stove fireplace, a musical armonica with 37 revolving glass hemispheres—not to mention his pointed lightning rod, which George the 3rd regarded as a Whig plot to attract lightning to government buildings for their destruction.

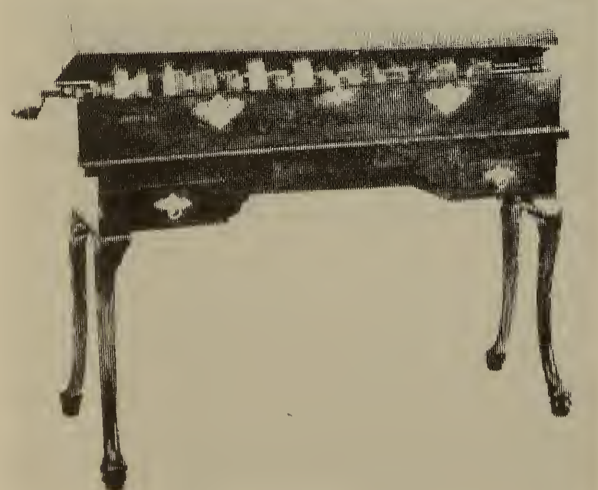

Fig. 6. Armonica (1762).

Franklin is known most widely for his successful venture into international affairs. A colonial patriot, he truly served his country unstintingly. He began at the age of 30, when he was appointed clerk (for 15 years) of the Philadelphia Assembly. Twelve years later he was elected to the Philadelphia Council and within three years an Alderman and Philadelphia member of the Assembly. He participated in the Carlisle Pow-wows (1753) with representatives of the Indian Confederation of Six Nations—his first diplomatic mission. The following year he proposed a similar plan of union at the Albany Congress. In 1757, at 51, he sailed to England as a special Assembly agent to seek military defense and tax relief. Five years later he returned, only to be sent back to England within two years. He became an important factor in the defeat of the Stamp Act in 1766 when, as the voice of America, he made a major address

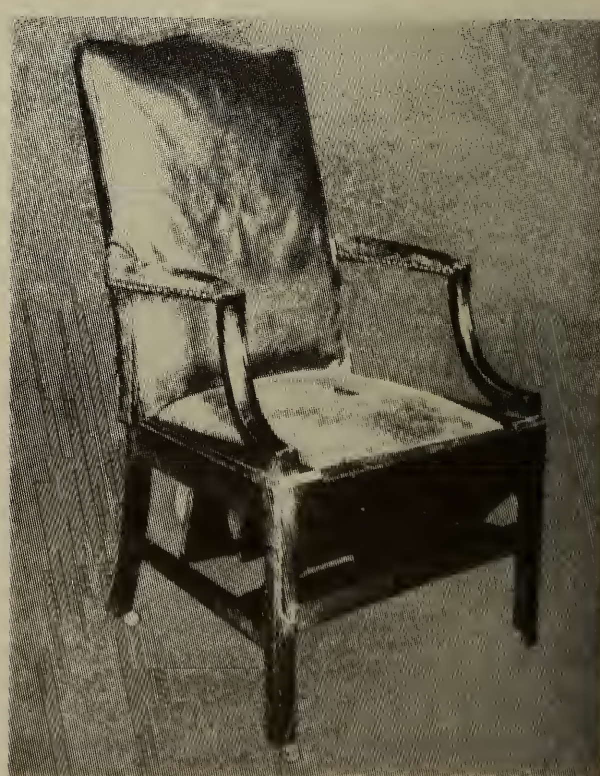

Fig. 7. Leather armchair (note folded ladder under seat) (1785—American Philosophical Society).

during the 11-hour debate by the House of Commons. Franklin has been regarded by some as "one of history's preeminent diplomats." In addition to his urbanity and versatility, Franklin found doors opened to him by virtue of his scientific prestige, which had preceded him. Five times he was elected to the Royal Society Council. On the other hand, he was *persona non grata* to George the 3rd, whose coronation he attended in 1761; the king, being indifferent to both science and trade, learned to dislike this colonial patriot more and more. A political storm arose when certain letters containing inflammatory comments by Thomas Hutchison, Governor of Massachusetts, were indiscreetly used by colonial agitators as evidence for having the governor deposed. Franklin publicly admitted on Christmas day 1773 that he had sent them to Boston for private circulation. He was summoned to appear before the Privy Council two weeks later, when he was summarily dismissed as deputy postmaster general; the petition for deposal was rejected. He departed from England in disgrace on May 5th, 1775, a trip saddened by news of his wife's death. Franklin's dual role (royal appointee and colonial agent) had raised doubts on both sides of the Atlantic as to his true loyalty. Until the Revolution to be sure, he was a moderate, attempting reconciliation, but thereafter there was no question as to his colonial patriotism.

The day after his arrival, he was elected a Pennsylvania delegate (its oldest member) to the Second Continental Congress. A year later he was a member of the Committee that drafted the Declaration of Independence. He was elected a Pennsylvania delegate to the Constitutional Convention. At 70 he was appointed one of the three Commissioners to negotiate treaties of amity and commerce abroad, particularly at the French court of the 22-year-old Louis the 16th and the 21-year-old Marie Antoinette. As he had been accompanied to London by his son William, so he now went with the latter's illegitimate son, William Temple.

Fig. 8. "A Genie D. Franklin" (1778—J. Fragonard).

He received personal acclaim by the French as a philosopher of the Enlightenment, due primarily to his scientific achievement. He was more or less the official representative of American learning abroad. His reception was greater than that for any other American before or after him. He was, indeed, the first American to attain a truly international reputation; his scientific prestige was America's greatest asset abroad. The simplicity of his sober attire (wigless, fur cap) in the country of the romantic J. J. Rouseau and his ready wit in the city of the satirist Voltaire endeared him to the populace. Despite his old age, Franklin was welcomed also by a galaxy of intelligent women; in the prevailing French mood of flirtation he charmed them with his almost Parisian gallantries and *bons mots*. At the same time he sought to promote the public understanding of remote America. (He never could refrain from hoaxes; the French novelist H. de Balzac remarked that Franklin was the inventor of the lightning rod, the hoax, and the republic.) The 1777 Saratoga defeat of the English commander (and dramatist) J. Burgoyne turned the tide of French sympathy toward America. Among his many duties Franklin recommended various individuals to Congress; among them were the 20-year old Marquis de Lafayette and the Prussian Baron von Steuben, both of whom became major generals in the colonial army. Franklin, together with commissioners John Adams and John Jay, signed the 1783 peace treaty in Paris. At 75, Franklin submitted his resignation but was not permitted to do so by Congress until four years later. Before he left Paris he served on a French Commission with the physician J. I. Guillotin; the chemist, A. L. Lavoisier, *et al*. to evaluate the claims of the Austrian charlatan physician F. A. Mesmer.

In 1787 he was a member (its oldest) of the Constitutional Convention. His compromise of a bicameral Congress satisfied both the proponents of equal state representation and their opponents, who demanded proportionate population consideration—adopted 17 September (Constitution Day) 1787. On September 16, 1788, at the age of 82, Franklin resigned his presidency of the special Pennsylvania Convention for ratification of the Constitution—the last Colony had approved it. His political career was ended; two years later he signed a memorial about slavery, his last act of public service.

Ever curious and industrious, Franklin had wistfully hoped to devote his retirement to scientific pursuits, but gout, bladder stone, and failing eyesight combined to produce a lingering painful illness. He died April 7, 1790. Four days later a cortege of 20,000 persons followed him mournfully from the State House (later Independence Hall) to the burial ground.

Our Franklin heritage is his full life as a wholesome person, who walked reverently in this wonder-full universe, and who touched his fellow sojourners with a loving heart and uplifting hands. He had personal integrity.

The Correct Identity of Stator bixae *(Drapiez) with Lectotype Designation (Coleoptera: Bruchidae)*

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ABSTRACT

Two species of Bruchidae, *Stator bixae* (Drapiez) from Brazil and French Guiana, and *S. championi* (Sharp) found from Costa Rica to Brazil, have been treated as 1 species. Both breed in seeds of *Bixa orellana* L. The 2 species are differentiated, and the lectotype of *S. bixae* is designated.

An examination of the type-specimens of *Stator bixae* (Drapiez) has revealed a misapplication of the name to a species now known as *Stator championi* (Sharp) described from Panama. A redescription of the true *bixae* and designation of the lectotype is presented, and characters distinguishing it from *championi* are given.

A number of references concerning the biology of "*Bruchus bixae*" appear in the literature, and these are discussed at the end of this paper.

Stator bixae Drapiez

Bruchus bixae Drapiez, 1820, p. 120; Gyllenhal *in* Schoenh. 1833, p. 32; Pic, 1913, p. 19; Everts, 1923, p. 199.
Bruchidius bixae: Herford, 1935, p. 16.
Acanthoscelides bixae: Blackwelder, 1946, p. 759.

Body length—2.5–2.75 mm; width—1.6–1.8 mm. Integument red to piceous, eyes black; vestiture of gray, golden, and dark brown fine setae in variable pattern (Figs. 1, 2).

Body subovate. Head subtriangular, eyes protruding, ocular sinus about one-third length of eye; frontal carina prominent, frons and clypeus finely punctate, frontoclypeal suture angulate; segments 4–11 of antenna slightly eccentric. Postocular fringe narrow, postocular patch of setae present. Pronotum subconical, lateral margins straight, disk evenly convex, finely, evenly, punctate, slightly depressed basally on each side of and at middle of basal lobe, lateral carina present only in basal one-third, nearly hidden by vestiture. Scutellum subquadrate, emarginate apically. Elytra as long as wide; striae not distorted, shallowly sulcate, only 2nd and 6th reaching basal margin, 3rd, 4th and 5th beginning basally on a level with base of scutellum, striae not coalescent apically. Pygidium in both sexes subtriangular, with 3 large subbasal yellow-gray spots, vestiture between spots sparse, becoming denser toward apex. Front and middle legs unmodified; entire hind coxal face densely, finely punctate; hind femur bicarinate on ventral margin, sulcate between carinae, mesal carina with acute subapical spine preceded by 2 or 3 setose notches, lateral carina sinuate subapically; hind tibia stout, ventral carina ending in short, acute mucro, lateral carina ending in short spine, lateroventral carina ending in sinus between mucro and lateral spine.

Male genitalia (Figs. 3, 4): median lobe broad; ventral valve triangular, ending in small tubercle; internal sac armed with acute, flat denticles in basal ½, with slender spicules in 2 membranous lateral sacs, and scattered short denticles in apical half; apex cylindrical, armed with many fine spicules. Lateral lobes arcuate, flattened, expanded then attenuated apically.

Stator bixae: Fig. 1, dorsal habitus, fully developed pattern; fig. 2, dorsal habitus, teneral pattern; fig. 3, ♂ genitalia, median lobe, ventral view; fig. 4, ♂ genitalia, lateral lobes, ventral view.

Type-locality.—"Bresil." Type-series (3) in the Institut Royal des Sciences Naturelles de Belgique, Brussels. Lectotype ♂ here designated with labels "Bresil," "coll. Dejean, Coll. Roelofs," "Bixae Hoffmansegg" agreeing with original description. My label "Lectotype, *Bruchus bixae* Drapiez, by Kingsolver" is attached to this specimen. Paralectotypes: 2 ♀♀, same data as for lectotype, and my labels indicating their designation are attached.

Stator bixae is known only from Brazil and French Guiana, but *championi* is found from Brazil to Costa Rica. Both species apparently breed only in the seeds of *Bixa orellana* L. (Bixaceae), a dye and drug-producing plant locally called *annatto*, which has a geographical distribution (probably artificial) from Mexico to Brazil. Standley (1923) includes a discussion of the various uses of its vegetative parts. Bridwell's biological notes (1923) apply to *championi* as determined by examination of his material in the United States National Museum of Natural History; and Champion's notes (1923) probably pertain to *championi*; but Evert's description (1923) indicates that he likely had *bixae*. Kingsolver (1970), in transferring the name *bixae* to *Stator*, used specimens now known to belong to *championi*, but the placement of both specific names in *Stator* is correct.

Stator championi can be distinguished from *bixae* by the broad, dark stripe bisecting the pronotal disk; the basal pygidial ornamentation of 3 white patches of setae set in a yellow, transverse band; and the apical two-thirds of the pygidium being nearly glabrous except for a very narrow medial line of setae. The male genitalia are also distinctive.

I have examined 2 series of *S. bixae*. In both series, 2 patterns of dorsal markings appeared: 1 with an abbreviated elytral pattern combined with a large basal thoracic spot (Fig. 2), 2 with a more developed elytral pattern associated with paired thoracic spots (Fig. 1), as illustrated from the lectotype.

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A New Species of Amblycerus *from Panama (Coleoptera: Bruchidae)*

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ABSTRACT

A new species of seed beetle, *Amblycerus tachygaliae*, destroys seeds of *Tachygalia versicolor* Standley and Williams, a large leguminous tree growing on Barro Colorado I., Panama. *A. tachygaliae* is described and figured, and *A. subflavidus* (Pic) is designated as a new synonym of *A. pollens* (Sharp).

Tachigalia versicolor Standley and Williams is a caesalpinoid leguminous tree 75–100 feet in height found in rain forests from Costa Rica to Panama. It produces great quantities of large, flat, single-seeded samaras each 6 to 7 cm long. From fruits collected on Barro Colorado I., the following new species of bruchid was reared.

Amblycerus tachigaliae **Kingsolver**

(Figs. 1–4)

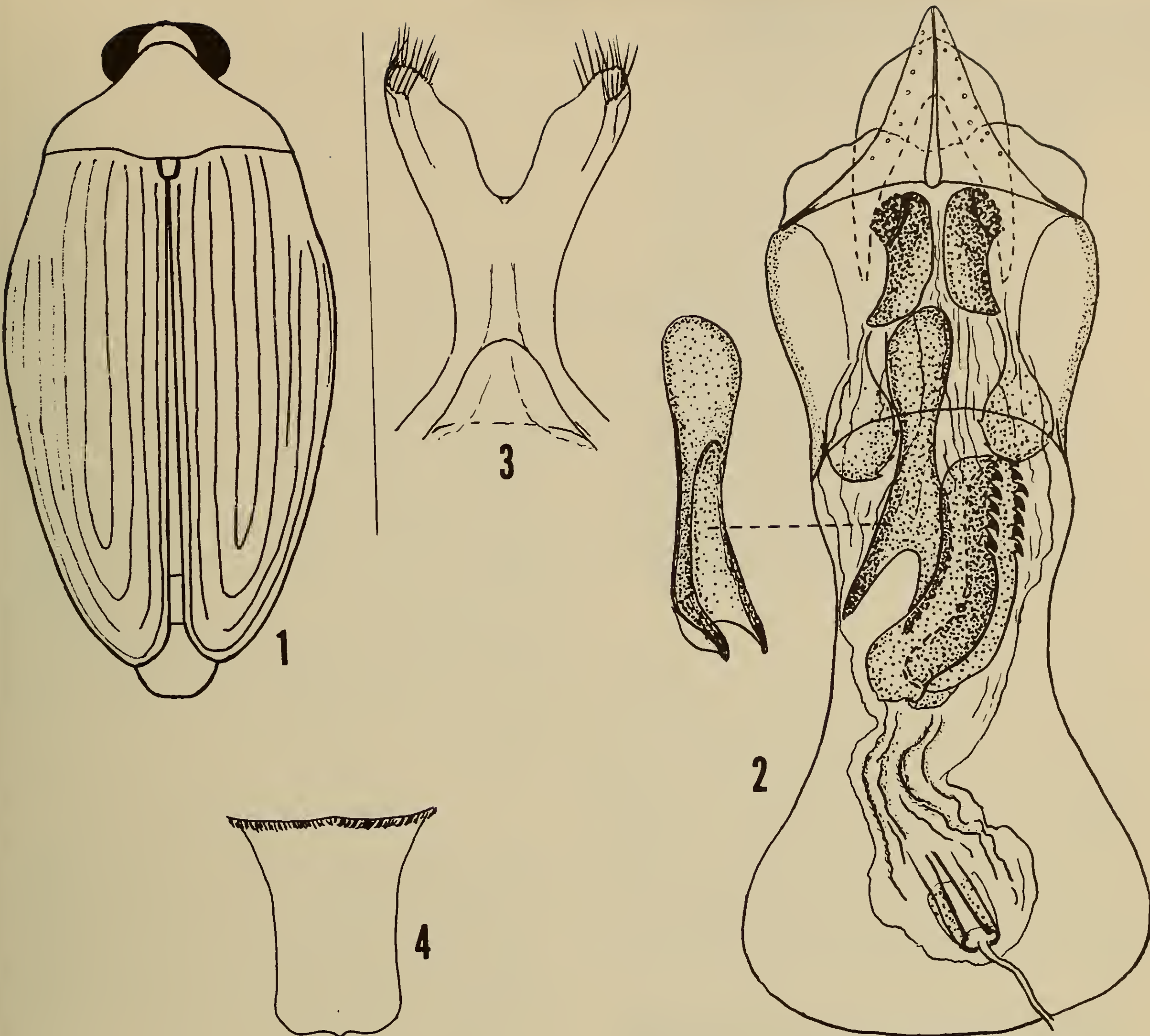
Body length—9.5 mm. Body width—5.5 mm. Pronotal length—2.5 mm. Pronotal width—4.5 mm.

Color.—Integument orange red in following areas: base of head, apex of clypeus, labrum, pronotum, elytra, abdomen, calcaria. Piceous suffused with reddish: prosternum, mesopleura, anterior portion of metepisternum, fore legs, antennae. Piceous: mesosternum, metasternum, middle and hind legs. Vestiture of very fine grayish hairs evenly distributed over body, those on orange red portions with golden sheen; pygidium with faint median line of closely spaced hairs.

Body elliptical, broad, somewhat depressed above. Head broad, short; eyes strongly protuberant, moderately incised at antennal insertion, postocular fringe of hair transverse; frons convex, vertex and frons finely punctate except along median; clypeus slightly depressed basally, finely punctate except on apical margin; labrum impunctate except for basal row of setae; antennal length equal to width of pronotal base, moderately serrate. Pronotum trapezoidal, lateral margins moderately arcuate, apex subtruncate; basal lobe broad, shallow; fine submarginal sulcus visible for nearly entire basal margin, in basal third of lateral margin, and on apical margin except for middle third, this sulcus hooked laterally around insertion of the 3 acromial setae on antero-lateral angle; disk finely punctulate with coarser punctures on slightly flattened lateral thirds of disk. Scutellum (Fig. 4) quadrate, slightly longer than wide, trilobed apically. Elytra somewhat depressed medially, intervals flat, all striae except 6 and 7 free apically. Pygidium nearly flat, oblique, slightly emarginate in male, evenly rounded in female. Prosternum narrow before coxae; intercoxal process narrow, apex slightly expanded, contiguous with vertical face of mesosternal lobe, hypomeron strongly concave, limited laterally by shiny sulcus. Metasternum slightly depressed along midline on posterior margin; postcoxal sulcus complete across midline, continuous with parasutural sulcus which extends to posterior margin; metepisternal sulcus right angled, extending halfway along pleural suture. Face of hind coxa densely covered with fine hairs in lateral three-fourths, sparsely, finely punctate; polished circular area surrounding trochanteral articulation with cluster of fine punctures. Hind femur relatively slender, ventral margin only slightly sinuate; hind tibia elliptical in cross section, ventral margin not flattened; outer calcar four-fifths as long as basitarsus, inner calcar half as long as outer calcar. Abdomen unmodified except last ventral sternum broadly emarginate in male, truncate in female.

Male genitalia.—Median lobe (Fig. 2) short, rather broad; ventral valve broadly triangular, lateral margins emarginate, dorsal valve semicircular apically, narrower at base than ventral valve; internal sac near apical orifice with paired lunate sclerites each with a coarse, granular posterolateral facet, middle of sac with an elongate, forked sclerite, and a pair of flat, serrate, curved blades. Lateral lobes as in Fig. 3.

Holotype.—♂, Panama: Barro Colorado I., Feb. 1975, Robin Foster, coll., reared from seeds of *Tachigalia versicolor*



Amblycerus tachygalia. Fig. 1, habitus, dorsal view; fig. 2, ♂ genitalia, median lobe, ventral view, with dorsal view of forked sclerite; fig. 3, ♂ genitalia, lateral lobes, ventral view; fig. 4, scutellum.

Standley & Williams. USNM Type #72813.

Allotype.—♀, Panama: Barro Colorado I., 24-II-1975, T. L. Erwin, coll., at light. In USNMNH Collection.

Paratype.—♂, Panama: Barro Colorado I., 10-III-1961, J. M. Campbell, coll., at light. In Canadian National Collection, Ottawa.

Amblycerus tachygaliae is most closely related to *A. pollens* (Sharp) (= *A. subflavidus* (Pic), NEW SYNONYMY). The abdomen in *A. pollens* is entirely black (red in *A. tachygaliae*), the hind femur is lobed on the medioventral carina (straight in *A. tachygaliae*), the ventral margin of the metepisternum has a fusiform, polished, finely ribbed boss (absent in *A. tachygaliae*), and marked differences are present in the ♂ genitalia. The two species are of comparable size and are the largest species in *Amblycerus* I have seen. The host plant of *A. pollens* is not known.

References Cited

Pic, M. 1902. Description de coléoptères nouveaux. Bruchidae de l'Amerique meridionale. Naturaliste 24: 172.

Sharp, D. 1885. Biologia Centralia-Americana, Insecta, Coleoptera, Bruchidae 5: 437–504.

THE AWARDS PROGRAM OF THE ACADEMY AND RECENT HONOREES

Five research scientists and two science teachers were recipients in the Spring of the Academy's awards for outstanding scientific achievement. The presentations were made at the Annual Awards Dinner meeting of the Academy on Thursday, March 18, 1976, at the Cosmos Club.

The following research investigators were honored: Dr. Julius E. Uhlaner (U. S. Army Research Institute for the Behavioral and Social Sciences) for Behavioral Sciences; Dr. Wayne A. Hendrickson (U. S. Naval Research Laboratory), for Biological Sciences; Dr. Gerard V. Trunk (U. S. Naval Research Laboratory) for Engineering Sciences; Dr. Charles H. Johnson (University of Maryland), for Mathematics; and Dr. William K. Rose (University of Maryland), for Physical Sciences.

Julius E. Uhlaner

In the area of Teaching of Science, the Awardee at the college level was Dr. Peggy Dixon of the Montgomery College Faculty. The recipient of the Berenice G. Lamberton Award for the Teaching of High School Science was Ms. Edith G. Durie of the West Springfield High School faculty.

Behavioral Sciences

Dr. Julius E. Uhlaner, Chief Psychologist of the U. S. Army and Technical Director of the Army Research Institute for the Behavioral and Social Sciences, and Adjunct Professor of Psychology at George Washington University, was cited for "his outstanding technical direction and leadership in Applied Psychology." As a psychologist, he is best known for contributions to military psychology, having spent the major part of his career as a civilian research psychologist in the Army. However, he also kept closely in touch with academia and industry. He is best known for some of his innovative contributions to the Army, having developed the first psychological military qualifications test legislated by Congress; introduced the use of the computer as a major tool and partner in Behavioral Science research; pioneered night vision testing research and driver research; introduced the first differential classification system based on psychological aptitude testing anywhere in the military services; pioneered the "system measurement bed," a methodology which influenced the field of industrial psychology; and fostered the interdisciplinary approach to much of his research. Also, he has exhibited very active professionalism, including the holding of elective offices in divisions of the American Psychological Association.

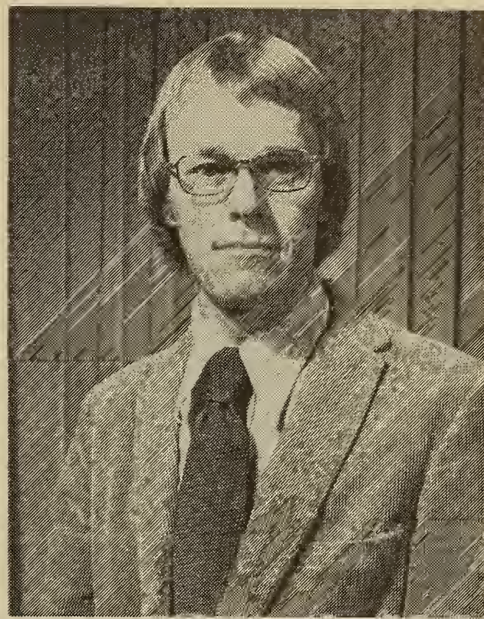
His awards in the Federal service include the Citation for Meritorious Civilian Service, 1960; Citation for Exceptional Civilian Service, 1969; and Citation for Outstanding Performance, 1972.

Dr. Uhlaner pursued a course of training and education in science, statistics, and graduate psychology. While earning his doctorate at New York University, he established a driver research laboratory. Later, he became associated with industry. It is this combination of experience and education which has led to his trademark for the conduct of research in the Behavioral Sciences—an interdisciplinary approach, systems oriented, and the utilization of research products.

In addition to his having been elected a Fellow of the Washington Academy of Sciences in 1963, he is also a Fellow of the American Psychological Association. Also, he is a Fellow of the Human Factors Society and the Iowa Academy of Sciences. Other learned societies of which he is a member are Operations Research Society of America, International Association of Applied Psychology, Psychonomics Society, and District of Columbia Psychological Association.

Biological Sciences

Dr. Wayne A. Hendrickson, Laboratory for the Structure of Matter, U. S. Naval Research Laboratory, was cited for "his significant contributions to knowledge of the structure of the active sites of oxygen-carrying molecules." He was born in Spring Valley, Wisconsin. His B.A. degree was completed in 1963 at the University of Wisconsin (River Falls). His Ph.D. degree in Biophysics was conferred by The Johns Hopkins University in 1968. Dr. Hendrickson was a postdoctoral fellow at Johns Hopkins for another year before being awarded



Wayne A. Hendrickson

an NRC Postdoctoral Research Associateship at the Naval Research Laboratory in 1969. Professional societies to which he belongs include the American Crystallographic Association and the American Society of Biological Chemists. His research interests are concerned with the structure and function of biological macromolecules as revealed by X-ray crystallography. Since 1971, Dr. Hendrickson has been a Research Biophysicist in the Laboratory for the Structure of Matter at the Naval Research Laboratory, Washington, D. C.

Engineering Sciences

Dr. Gerard V. Trunk, U. S. Naval Research Laboratory, was cited for "his contributions to theory and practice of processing radar signals in clutter." Dr. Trunk was born in Baltimore, Maryland on May 9, 1942. He received the B.E.S. and Ph.D. degrees from The Johns Hopkins University in 1963 and 1967, respectively. Since his graduation in 1967, he has been employed by the Radar Division of the Naval Research Laboratory, Washington, D. C. During the 1974–1975 academic year, he was on sabbatical leave and taught at The Johns Hopkins University.

His research areas are signal detection,

Gerard V. Trunk

estimation theory, and pattern recognition. He has done considerable work in the area óf sea clutter return from high-resolution radars. This work entailed understanding the basic nature of high-resolution sea clutter, finding a statistical description of it, and of generating an optimal detector. At the present time, he is involved in developing tracking systems for radar data supplied by multiple radars located either on the same ship or on different ships.

Dr. Trunk is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

Mathematics

Dr. Charles H. Johnson, University of Maryland, was cited for ''his outstanding contributions in matrix theory, stability and eigenvalue location.'' The theory of matrices, or linear transformations, is a field of broad applicability within mathematics as well as to the sciences generally. Dr. Johnson's primary interests within matrix theory include eigenvalue location, stability matrices and the numerical range, entry-wise nonnegative and stochastic matrices, and Hadamard products. The numerical range is the set of all values taken on over the surface of the unit ball by the quadratic form of a matrix. Dr. Johnson is also interested in the relation of such aspects of matrix theory to mathematical economics and modelling, discrete dynamical systems such as those of demography, and to combinatorial mathematics.

He was born in Elkhart, Indiana on January 28, 1948. Dr. Johnson received his B.A. degree from Northwestern University in 1969 and his Ph.D. in mathematics and economics from the California Institute of Technology in 1972. From 1972 to 1974, he was an NAS–NRC postdoctoral research fellow in the Applied Mathematics Division at the National Bureau of Standards. In 1974, he came to the University of Maryland, where he is now an Assistant Professor. Also, he serves as a Consultant at the National Bureau of Standards and as a Visiting Staff Member at the Los Alamos Scientific Laboratories. He has served as a Visiting Lecturer for the Society of Industrial and Applied Mathematics and also as an invited speaker at meetings of the American Mathematical Society and Mathematical Association of America. He is the author of more than 40 research papers.

Charles H. Johnson

Physical Sciences

Dr. William K. Rose, University of Maryland, was cited for his "important contributions to our understanding of highly evolved stars." He was born in Ossining, New York on August 30, 1935. Dr. Rose received the A.B. and Ph.D. degrees from Columbia University in 1957 and 1963, respectively. He was a research scientist at the U. S. Naval Research Laboratory from 1961 to 1962 and at the Department of Astrophysical Sciences at Princeton University from 1963 to 1967. In 1957, he joined the M.I.T. Physics Department, where he held the positions of Assistant Professor and of Associate Professor. Since 1971, Dr. Rose has been an Associate Professor in the Department of Physics and Astronomy at the University of Maryland.

Dr. Rose's research has included early work on masers, radio astronomy, and infrared astronomy from balloons. Since 1965, he has worked on a number of problems in theoretical astrophysics. Most of his theoretical research has been concerned with the physical properties and evolution of stars. Dr. Rose has developed theories relating to the evolution of the sun, the origin of planetary nebulae and novae, X-ray emission from compact objects, pulsar radiation, and the physical state of the interiors of red giants and neutron stars. Recently, Dr. Rose has investigated several problems in the field of plasma astrophysics.

William K. Rose

Peggy Dixon

Teaching of Science
(College Level)

Dr. Peggy Dixon, Montgomery College, was cited for "improving, and gaining recognition for, local and national community college science teaching." She received her A.B. degree from Western Reserve University and her M.S. and Ph.D. degrees in Physics from the University of Maryland. Memberships in scientific organizations include the following: American Association of Physics Teachers (Member-at-large of Executive Board, 1973–1976; Vice-President of Chesapeake Section, 1976– ; Representative to Metric Education Committees, 1974– ; Chairman, Panel on Physics in Two-year Colleges (PPTYC) of the Commission on College Physics, 1968–1970); National Science Teachers Association;

Edith G. Durie

American Association for the Advancement of Science; American Association of University Professors; Sigma Xi; and Sigma Pi Sigma.

Her professional experience includes three years as Research Associate, University of Maryland, and fifteen years at Montgomery College, teaching Mathematics and Geology as well as Physics and Physical Science.

Some significant educational projects with which she has been associated are the following: Resource Packet Project of PPTYC; NSF–COSIP Grant, Co-Director, for articulation in all sciences between the University of Maryland and all Maryland Community Colleges, 1970–1974; development and teaching of two honors courses at Montgomery College (as a member of the Honors Program Committee over a period of ten years).

Teaching of Science
(High School Level)
(The Berenice G. Lamberton Award)

Ms. Edythe G. Durie, West Springfield High School, was cited for "being an outstanding science teacher who is supportive of the student on and off the campus." She was born June 3, 1915 in Hellier, Kentucky. Ms. Durie received her A.B. degree from Marshall University in 1937 and her M.S. degree from the Graduate School of Medicine, University of Pennsylvania, 1942. She has also done graduate study at the University of Kentucky and at the University of California.

From 1942 to 1952, she was supervising bacteriologist for the Virginia Department of Agriculture. Later, she taught at Hopewell High School, Hopewell, Virginia, and at the Orleans American High School in Orleans, France. In 1961, she came to Fairfax County and taught at Robert E. Lee High School in Springfield, Virginia. She transferred to West Springfield High School when it opened in 1966. She has been Science Department Chairman there since 1967.

Professional organizations with which she has been associated are the following: National Science Teachers Association; Virginia Academy of Science; W. S. Junior Academy of Sciences, Washington Academy of Sciences; and Joint Board on Science and Engineering Education (currently serving as Chairman of the group.—

Kelso B. Morris, *General Chairman*

NEW FELLOWS

William W. Cantelo, Research Entomologist, USDA, in recognition of his contributions to entomology, especially to insect behavior in response to blacklight traps and to pheromones. *Sponsors*: Floyd L. Smith, Richard H. Foote.

Lowell E. Campbell, Project Engineer, USDA, in recognition of science education activities on JBSEE, 1960–65, and professional contributions to electrical equipment performance and utilization in agriculture, including recent establishment with Dr. H. M. Cathey, USDA, that vegetative growth in plants is dependent on level and duration of radiation in the 400 to 850 nm region without spectral preference. *Sponsors*: Hajime Ota, Henry M. Cathey, Milton S. Schechter.

Satya D. Dubey, Chief, Statistical Evaluation Branch, Bureau of Drugs, Food & Drug Adm., in recognition of his contributions to mathematical statistics and in particular to his publications on Weibull and other distributions. *Sponsors*: Grover C. Sherlin, Joan R. Rosenblatt, Nelson W. Rupp.

Alan O. Plait, Principal Staff Engineer, Computer Sciences Corp., in recognition of his extensive educational programs in training persons in the mathematical arts and sciences for application to engineering and quality assurance problems and for his work in transfering the technology of the assurance sciences to new fields such as housing and environmental problems. *Sponsors*: Grover C. Sherlin, Joan R. Rosenblatt, Nelson W. Rupp.

James M. Schalk, Research Entomologist, USDA, in recognition of contributions in entomology, particularly on developing host plants resistant lines of forage and vegetable crops to arthropod pests. *Sponsors*: Floyd L. Smith, Richard H. Foote.

Herbert H. Snyder, Prof. Mathematics, Southern Ill. Univ. at Carbondale, in recognition of his contributions to electromagnetic theory and in particular to the mathematical theory of propagation of electromagnetic waves in periodic structures and the interactions of such waves with beams of charged particles; and for his contribution to the theory of regular functions on linear associative algebras. *Sponsors*: Joan R. Rosenblatt, Florence H. Forziati.

Manya B. Stoetzel, Research Entomologist, USDA, in recognition of her contribution to the biosystematics of scale insects, and in particular to her studies on the life histories and the adult male and immature stages of the aspidiotine scales. *Sponsors*: Richard H. Foote, Louise M. Russell, R. R. Colwell.

Howard E. Waterworth, Research Plant Pathologist, US Plant Introduction Station, Glenn Dale, Md., in recognition of his contributions to Plant Pathology, especially in the field of virology and serology. *Sponsors*: Floyd L. Smith, H. Ota, Richard H. Foote.

Sajjad H. Durrani, Senior Engineer, Goddard Space Flight Ctr., in recognition of his contributions to the conceptual design and analysis of space communication systems. *Sponsors*: Edward Wolff, George Abraham, Emanuel Brancato.

Lloyd Knutson, Chairman, Insect Identification and Beneficial Insect Introduction Institute, ARS, USDA, in recognition of his outstanding research contributions to the systematics and taxonomy of snail-killing flies and his leadership as Chairman of ARS's Insect Identification & Beneficial Insect Introduction Institute at Beltsville. *Sponsors*: Richard H. Foote, Louise M. Russell, Ashley H. Gurney.

Kendall G. Powers, Research Parasitologist, NIH, in recognition of his contributions in the field of chemotherapy and immunology of parasitic diseases; particularly malaria and schistosomiasis. *Sponsor*: James H. Turner.

Roger H. Lawson, Research Pathologist, USDA, in recognition of his contributions to an understanding of viral cause and identity of diseases of orchids and chrysanthemums, and of his studies on ultrastructural cytology and the development of inclusion bodies associated with plant virus infection. *Sponsors*: Henry M. Cathey, Lloyd F. Smith.

Ralph E. Webb, Research Entomologist, USDA, in recognition of his contributions in entomology, especially his research on the biology and control of insect pests of ornamentals and vegetable crops, also induced and natural resistance of plants to insect attack. *Sponsors*: Floyd L. Smith, Richard H. Foote.

Armand B. Weiss, Director, Systems Integration, Federal Energy Adm., in recognition of his contribution to operations research, in particular his research on quantitative aspects of policy level decision making, his research leading to improved economic models of logistic support processes, and his significant contributions to modelling the national energy needs, distribution and resources. *Sponsors*: John Honig, Jean K. Boek.

Robert L. Gluckstern, Chancellor, University of Maryland, in recognition of his scientific contributions to high energy physics and his design of cyclotrons. *Sponsors*: Joseph M. Marchello, S. N. Foner.

SCIENTISTS IN THE NEWS

Contributions in this section of your Journal are earnestly solicited. They should be typed double-spaced and sent to the Editor three months preceeding the issue for which they are intended.

HARRY DIAMOND LABORATORIES

Frank Reggia has received an Army R & D achievement award for his pioneering efforts and outstanding accomplishments in the design, development and demonstrated use of a novel group of conformal antennas for military systems. These high performance antenna designs are capable of eliminating many mechanical and electrical problems while enhancing overall system performance. The

antennas are constructed as an integral part of a body, at any position along its length and flush with the surface.

Born in Northumberland, PA, Frank married the former Betty Jo Patterson of Clarksville, Arkansas in 1945. The couple have two sons James Allen, 26, and Daniel Lee, 22, and currently reside in Bethesda, MD. Frank has attended George Washington University and the University of Maryland majoring in Engineering and Physics. In 1970 he earned a BS (cum laude) and in 1971 a MS from Bucknell University, both in electrical engineering. He is a member of Tau Beta Pi, a National Engineering Honor Society; a Fellow, Institute of Electrical and Electronic Engineers; a Fellow, American Association for Advancement of Science; and a Fellow, Washington Academy of Sciences. In addition, he is the author of 50 technical articles in the microwave field, and holds 16 patents on microwave ferrites and acoustic components.

NATIONAL BUREAU OF STANDARDS

Dr. Florence Forziati, President-Elect, Washington Academy of Sciences, presented a scroll commemorating the 75th anniversary of NBS to Dr. Ernest Ambler, Acting Director, NBS, on March 4, 1976. Dr. Ambler's acknowledgment follows:

Dear Dr. Forziati:

I wish to express my appreciation to you for the beautiful commemorative scroll from the Washington Academy of Sciences which you presented to the Bureau yesterday, on the occasion of our 75th birthday.

I am sure that the Bureau and its staff members will continue in the future, the close relationship with the Academy which has existed so many years in the past.

I think it was especially appropriate that the presentation be made by you, because of your employment for so many years at the Bureau as a scientist.

Sincerely,

Ernest Ambler
Acting Director

NATIONAL INSTITUTES OF HEALTH

David B. Scott has been named Director of the National Institute of Dental Research. Dr. Scott was dean of the School of Dentistry, Case Western Reserve University.

"Dr. Scott . . . brings to this post an outstanding background in dental research, education, and administration," said Dr. Donald S. Fredrickson, NIH Director.

The new NIDR Director joined the faculty of Western Reserve University in 1965 as the Thomas J. Hill Distinguished Professor of Physical Biology in the School of Dentistry and was jointly appointed as professor of anatomy in the School of Medicine. Following the federation of the University with the Case Institute of Technology to form Case Western Reserve University, Dr. Scott became dean of the School of Dentistry in 1969.

Dr. Scott, whose appointment was effective Jan. 1, has returned to NIH, where he served from 1944 to 1965.

He was with the Dental Section, Division of Physiology, Experimental Biology and Medicine from 1944 until 1948, when the NIDR was established, and he served as chief of the Institute's Laboratory of Histology and Pathology from 1956 to 1965.

Dr. Scott received the B.A. degree in physical biology from Brown University in 1939 and his D.D.S. from the Baltimore College of Dental Surgery, University of Maryland, in 1943. The next year he was awarded the M.S. degree from the University of Rochester where he was a Carnegie Fellow. In 1956, he received one of the awards given the 10 most outstanding young men in Government service by the Arthur S. Flemming Awards Commission.

Dr. Scott was cited for his development of new methods for applying the electron microscope to the study of enamel and dentin, and the development of new techniques for studying the structure of teeth. Other awards accorded Dr. Scott include: honorary membership, Finnish Dental Association; honorary lecturer, Tokyo Dental College, and the International Association for Dental Research Award for Research in Mineralization, 1968.

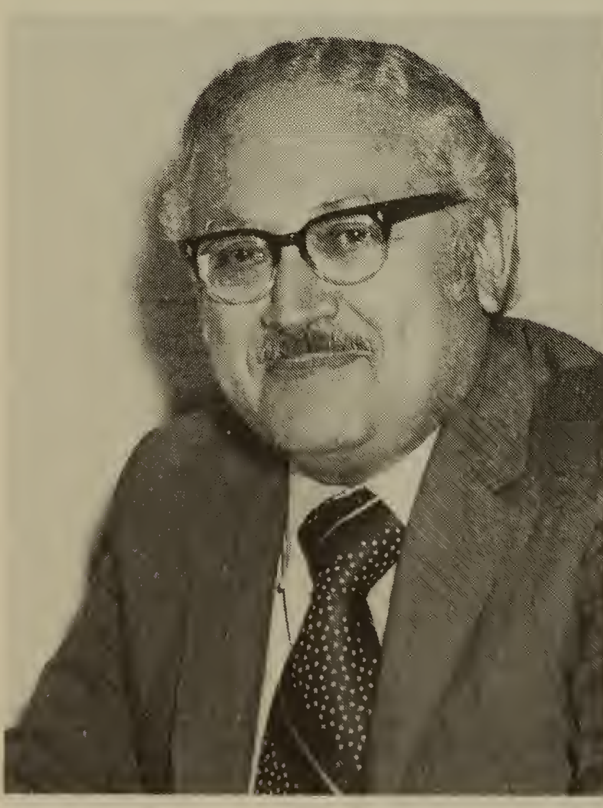
Dr. Scott is a Fellow, American Association for the Advancement of Science, a Fellow, the American College of Dentists and the International College of Dentists; and a Fellow, Washington Academy of Sciences.

He has served in scientific posts with the Federation Dentaire Internationale.

He is a member of the Electron Microscope Society of America, the American Dental Association, and is president of the International Association for Dental Research.

NATIONAL OCEAN SURVEY

Hyman Orlin, author, teacher, mathematician, and geodesist, has retired after more than 33 years of service with the Federal government. Orlin, who leaves the post of Chief Scientist of the National Oceanic and Atmospheric Administration's National Ocean Survey, will become Senior Scientist with the National Academy of Sciences in Washington, D. C., later this month.



Hyman Orlin

A recognized authority in the field of geodesy, Orlin has been with NOAA's National Ocean Survey and its predecessor, the Coast and Geodetic Survey, since 1947 when he was employed as mathematician. In 1969, he was appointed Special Assistant to the Director for Earth Science Activities as the principal advisor in geophysical matters.

Orlin has represented NOAA at International Astronomical Union Symposia, since 1958. He has served as Co-Chairman of the Sea Bottom Surveys Panel of the U. S.–Japan Natural Resources Committee, and has held discussions with Japanese officials on international cooperative programs and the exchange of scientists. He is an authority on the geodetic aspects of offshore boundaries and Law of the Sea and serves as advisor to and member of the U. S. Interagency Committee on Law of the Sea.

Orlin has taken an active role in intergovernmental agency efforts which have resulted in improved services and products for the general public. He has served as president of the Geodesy Section of the American Geophysical Union, and has received the coveted Silver Beaver Award for his contribution to Boy Scouting. In 1970, he was presented the Heiskanen Geodesy Award from Ohio State University where he had received his doctorate in geodetic science in 1962.

As an author, Orlin has published numerous scientific articles on his gravity observations, geodetic astronomy, geophysics, law of the sea and the earth's external gravity field. He has taught graduate and undergraduate courses in geodetic sciences at George Washington University and is coordinator for the Geodetic and Cartographic Science and the Oceanographic Science programs at the University.

A native of New York City, Orlin has received degrees from the City College of New York, George Washington University, and Ohio State University. He and his wife, the former Lenore Driller of Bronx, N. Y., live in Silver Spring, Md. He is a member of Sigma Xi and the International Astronomical Union and a Fellow of the American Geophysical Union and the Washington Academy of Sciences.

NAVAL RESEARCH LABORATORY

Dr. Isabella L. Karle received the American Chemical Society's 1976 Garvan medal and $2,000 on April 5 during the Society's Centennial meeting in New York City.

Dr. Karle was named to present the award address this year on April 8 at a symposium arranged by the Biochemistry Division of the ACS. Among the speakers at this symposium was her daughter, Dr. Louise Karle Hanson, a spectroscopist at the National Institute of Health. Coincidentally, Dr. Karle, who is also president of the American Crystallographic Association, presented greetings from that society to the ACS at a ceremonial session, along with the presidents of many other scientific societies from the United States and around the world.

An authority in x-ray crystallography, Dr. Karle has developed a practical procedure to determine molecular structures of complex substances, including materials of biological and medical interest, that previously could not be studied by x-ray techniques. Before she introduced her method, the direct method of phase determination, scientists were limited to restricted types of compounds that could be examined by x-ray crystallography —the best technique to determine the three-dimensional atomic arrangement in a molecule. In particular, compounds of biological interest, because they are composed of lightweight elements, were not amenable to the x-ray technique. Dr. Karle's method changed that.

Dr. Karle is recognized for her structural investigations employing the new method. She has elucidated structural features in antibiotics; radiation damage to genetic material; heart drugs; drug antagonists; frog venoms; compounds induced by ultraviolet radiation and associated with primary visual response; and ion-transport in biological systems.

A native of Detroit, she received the B.S. in 1941, the M.S. in 1942, and the Ph.D. in 1944 at the University of Michigan, completing the doctorate at the age of 22. She remained at the University of Michigan as an instructor in chemistry until 1946, when she joined the Naval Research Laboratory as a research physicist. Author of more than 100 papers on electron and x-ray diffraction studies of crystal and molecular structures, Dr. Karle has supervised several programs of postdoctrol research and maintains collaborative research projects with government laboratories and research institutions throughout the world.

Honors accorded Dr. Karle are the Navy Superior Civilian Service Award (1965), the Naval Research Laboratory's Scientific Research Society of American Applied Science Award (1967), the Society of Women Engineers Annual Achievement Award (1968), the Hillebrand Award of the American Chemical Society's Washington section (1969), the Federal Woman's Award (1973), and membership in Phi Beta Kappa and Sigma Xi.

She is a fellow of the Washington Academy of Sciences, an honorary life member of the Society of Women Engineers, and a member of the U. S. A. National Committee for Crystallography, the American Crystallographic Association, the American Physical Society, the American Chemical Society, the American Association for the Advancement of Science, the Biophysical Society, the Research Society of America, and the Advisory Board of the publication *Biopolymers,* an international journal of research on biological molecules.

In addition to the honorarium and the gold Garvan Medal, Dr. Karle received a bronze replica of the medal. The award was established in 1936 through a donation from Francis P. Garvan and is supported by a fund set up at that time.

Norman H. C. Griffiths

Norman H. C. Griffiths throughout his professional career served his family, Howard University, and the world. He was a skilled prosthodontist, educator, researcher, and humanitarian. Dr. Griffiths passed away quietly on June 22, 1976 in the Howard University Hospital after a lengthy illness. He would have retired from his faculty position at the University on June 30, 1976 after 28 years of full-time service.

Dr. Griffiths graduated from the Howard University College of Dentistry in 1947 with honors. He received his graduate education at Northwestern University, where he earned the M.S.D. Degree in 1948 and at the University of Pennsylvania where he received his diploma in Prosthetic Dentistry in 1953 and the Doctor of Science Degree in 1957. He was first appointed to the dental faculty of Howard University in 1948 as an Assistant Professor.

During his very active career in teaching and dental practice, he spent many hours devoting his professional services to hospitals in the Washington area and lecturing to state, national, and local dental societies throughout the United States.

Dr. Griffiths has been an ambassador of health and the College's international faculty member. He taught and provided dental health care in India, Africa, Egypt, Ceylon, the West Indies and Europe. He spent 2 tours of duty on the S. S. Hope—the American Hospital Ship—where he provided dental services in Guinea, West Africa. He subsequently served as a consultant and advisor to the Hope staff.

His long list of honors and service include (President of the Caribbean American Intercultural Organization; Visiting Professor, University of Ceylon; Visiting Professor in India and Egypt on a U. S. State Department grant; member, Washington Academy of Sciences; Past President, Chi Delta Mu fraternity; Past State Vice President, National Dental Association; Past President, Pi Pi Chapter, Omicron Kappa Upsilon, the dental honor society; and the American Cleft Palate Association.

Professor Griffiths has made numerous contributions to the dental literature in his field of removable prosthodontics. His articles appear in the Journal of Dental Research; the Bulletin of the National Dental Association; Journal of Dental Education; Journal of the American Dental Association; Journal of the D. C. Dental Society, and the Egyptian Dental Journal.

His scholarly lectures and clinical expertise in the treatment of patients with missing teeth and other oral disorders will be missed by his professional colleagues, the faculty, staff, and students of the College of Dentistry. He has made special contributions to the field of prosthodontics through advances in technical and clinical diagnostic procedures for patients with missing teeth.

Dr. Griffiths is survived by his devoted wife Peggy S. and six children: Stephanie Denise, Dwight Norman, Michael Craig, Arthur Alexander, Peggy Manel, and Jacqueline Deneen; one sister, Stephanie G. Brown; and a host of relatives, colleagues, and friends.

Marjorie Hooker

Marjorie Hooker, 67, a geologist with the U. S. Geological Survey for nearly 30 years, died of cancer May 4, 1976.

With the Survey since 1947, she was responsible for abstracting geological literature, compiling data on the composition of igneous and metamorphic rocks of the world, and for international correlation of chemical data on granitic rocks.

Miss Hooker had received worldwide recognition for her work in scientific bibliography and for her activities with international scientific societies.

Born in Flushing, N.Y., she was a graduate of Hunter College and received a master's degree in geology from Syracuse University. She took graduate work at Columbia University.

She worked for 4 years as a mineral resource analyst with the State Department before joining the Geological Survey.

As organizer of abstracts from America for "Mineralogical Abstracts" since 1969, Miss Hooker had published 64 papers and was an adviser on chemical data.

She helped organize conferences for international societies, developed new programs in mineralogical and petrologic studies, and corresponded extensively with geologists all over the world. Miss Hooker had been a delegate to 4 international geological congresses, including the one in Prague in 1968 that was interrupted by the Soviet invasion.

She was a fellow of the Mineralogical Society of America, the Geological Society of London and the American Association for the Advancement of Science. She also was a member of the American Geophysical Union, the American Institute of Mining Engineers, the Association of Earth Science Editors and the mineralogical societies of Great Britain, France, Canada, Switzerland and Japan.

Miss Hooker, who lived at 2018 Luzerne Ave., Silver Spring, had served as a judge at area science fairs. She had been active in the North Woodside–Montgomery Hills Citizens Association for 22 years and had served as a trustee of the Woodlin Elementary School PTA in Silver Spring.

She is survived by two sisters, Elsie A. Hooker, of Flushing, and Vera H. Heidrick, of Addison, N. Y.

Instructions to Contributors

General

Type manuscripts on white bond paper either 8½ by 11 or 8 by 10½ inches. Double space all lines, including those in abstracts, tables, legends, quoted matter, acknowledgments, and references cited. Number pages consecutively. Place your name and complete address in the upper right hand corner of the title page.

Title, Author, and Affiliation

Page 1 of your manuscript should contain only this information and your name and address. Choose a concise but complete and meaningful title. In research papers concerning biological subjects, include an indication of the order and family of the taxa discussed. Academic degrees will not normally be included unless the author so specifies. If possible, combine your affiliation and mailing address (including Zip) so that readers can write to you directly.

Abstract

Type on a separate sheet at the end of the manuscript. Make the abstract intelligible without reference to the text of the paper. Write an informative digest of the significant content and conclusions, not a mere description. Generally, the abstract should not exceed 3% of the text.

Footnotes

Use footnotes as sparingly as possible. Number text footnotes consecutively with Arabic numerals and type them on a separate sheet of paper at the end of the manuscript. Type table footnotes, if any, below each pertinent table on the same page.

Illustrations and Legends

The quality of all original illustrations must be high enough to facilitate good offset reproduction. They should have ample margins and be drawn on heavy stock or fastened to stiff cardboard to prevent bending. They should be proportioned to column (1 x 3) or page (2 x 3) type-dimensions, leaving space for legend material. Photographs should have a glossy finish. They reproduce best when the contrast is fairly high. Identify each illustration with number and author in light pencil marks on the reverse side. Submit all illustrations separately – please do not glue or clip them to the pages of the manuscript.

Do not type or write legends directly on the illustrations. Type legends on a separate sheet or sheets at the end of the manuscript. Indicate where you want illustrations to appear in the printed paper by writing the figure numbers lightly in the text margins, and be sure that each figure is properly referenced in the text itself. Original "art" will be returned only at the author's request and expense.

Tables

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Directory Issue

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Directory, 1976:

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ACADEMY OFFICE

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The Journal

This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

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Obtainable from the Academy office (address at bottom of opposite column): **Proceedings:** Vols. 1-13 (1898–1910) **Index:** To Vols. 1-13 of the *Proceedings* and Vols. 1-40 of the *Journal* **Journal:** Back issues, volumes, and sets (Vols. 1-62, 1911-1972) and all current issues.

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DELEGATES TO THE WASHINGTON ACADEMY OF SCIENCES, REPRESENTING THE LOCAL AFFILIATED SOCIETIES

Philosophical Society of Washington	James F. Goff
Anthropological Society of Washington	Jean K. Boek
Biological Society of Washington	Inactive
Chemical Society of Washington	Delegate not appointed
Entomological Society of Washington	Maynard Ramsay
National Geographic Society	T. Dale Stewart
Geological Society of Washington	Marian M. Schnepfe
Medical Society of the District of Columbia	Inactive
Columbia Historical Society	Paul H. Oehser
Botanical Society of Washington	Conrad B. Link
Society of American Foresters	Thomas B. Glazebrook
Washington Society of Engineers	George Abraham
Institute of Electrical and Electronics Engineers	George Abraham
American Society of Mechanical Engineers	Michael Chi
Helminthological Society of Washington	Robert S. Isenstein
American Society for Microbiology	Delegate not appointed
Society of American Military Engineers	H.P. Demuth
American Society of Civil Engineers	Shou Shan Fan
Society for Experimental Biology and Medicine	Donald Flick
American Society for Metals	Glen W. Wensch
International Association of Dental Research	William V. Loebenstein
American Institute of Aeronautics and Astronautics	Franklin Ross
American Meteorological Society	A. James Wagner
Insecticide Society of Washington	Robert J. Argauer
Acoustical Society of America	Delegate not appointed
American Nuclear Society	Dick Duffey
Institute of Food Technologists	William Sulzbacher
American Ceramic Society	Inactive
Electrochemical Society	Delegate not appointed
Washington History of Science Club	Inactive
American Association of Physics Teachers	Bernard B. Watson
Optical Society of America	Ronald W. Waynant
American Society of Plant Physiologists	Walter Shropshire
Washington Operations Research Council	John G. Honig
Instrument Society of America	Inactive
American Institute of Mining, Metallurgical and Petroleum Engineers	Carl H. Cotterill
National Capitol Astronomers	Delegate not appointed
Mathematical Association of America	Patrick Hayes
D.C. Institute of Chemists	Miloslav Recheigl, Jr.
D.C. Psychological Association	John O'Hare
The Washington Paint Technical Group	Paul G. Campbell

Delegates continue in office until new selections are made by the representative societies.

THE DIRECTORY OF THE ACADEMY FOR 1976

Foreword

The present, 51st issue of the Academy's directory is again this year issued as part of the September number of the Journal. As in previous years, the alphabetical listing is based on a postcard questionnaire sent to the Academy membership. Members were asked to update the data concerning address and membership in affiliated societies by June 30, 1976. In cases in which cards were not received by that date, the address appears as it was used during 1976, and the remaining data were taken from the directory for 1975. Corrections should be called to the attention of the Academy office.

Code for Affiliated Societies, and Society Officers

1 The Philosophical Society of Washington (1898)

President:	Robert J. Rubin, 3308 McKinley St., N.W., Washington, D.C. 20015
Vice-President:	Paul A. Willis, 2824 W. George Mason Rd., Falls Church, Va. 22042
Secretary:	James F. Goff, 3405 34th Pl., N.W., Washington, D.C. 20016
Delegate:	James F. Goff

2 Anthropological Society of Washington (1898)

President:	Robert Humphrey, George Washington Univ., Washington, D.C. 20037
President-elect:	Priscilla Reining, Catholic Univ. of America, Washington, D.C. 20064
Secretary:	Mary F. Gallager, American Univ., Washington, D.C. 20016
Delegate:	Jean K. Boek, National Graduate Univ., 3408 Wisconsin Ave., N.W., Washington, D.C. 20016

3 Biological Society of Washington (1898)

President:	Joseph Rosewater, Smithsonian Institution, Washington, D.C. 20560
Secretary:	Richard C. Banks, Smithsonian Institution, Washington, D.C. 20560

4 Chemical Society of Washington (1898)

President:	Robert F. Cozzens, George Mason Univ., Fairfax, Va. 22030
President-elect:	David Venezky, Naval Res. Lab., Washington, D.C. 20375
Secretary:	John Moody, NBS, Chemistry, Bldg. 222, Washington, D.C. 20234
Delegate:	None appointed

5 Entomological Society of Washington (1898)

President:	H. Ivan Rainwater, Rm. 635, Federal Bldg., Hyattsville, Md. 20782
President-elect:	George C. Steyskal, W-617, NMNH, Washington, D.C. 20560
Secretary:	Theodore J. Spilman, W-605, NMNH, Washington, D.C. 20560
Delegate:	Maynard J. Ramsay, Rm. 660, Federal Bldg., Hyattsville, Md. 20782

6 National Geographic Society (1898)

President:	Robert E. Doyle, National Geographic Society, Washington, D.C. 20036
Chairman:	Melvin M. Payne, National Geographic Society, Washington, D.C. 20036
Secretary:	Owen R. Anderson, National Geographic Society, Washington, D.C. 20036
Delegate:	T. Dale Stewart, Smithsonian Institution, Museum of Natural History, Washington, D.C. 20560

7 Geological Society of Washington (1898)

President:	Joshua I. Tracey, Jr., U.S. Geological Survey, Reston, Va. 22092
Vice-President:	Dallas L. Peck, U.S. Geological Survey, Reston, Va. 22092
Secretary:	Penelope M. Hanshaw, U.S. Geological Survey, Reston, Va. 22092
Delegate:	Marian M. Schnepfe, 2019 Eye St. N.W. #402, Washington, D.C. 20006

8 Medical Society of the District of Columbia (1898)

President:	William S. McCune
President-elect:	Frank S. Bacon
Secretary:	Thomas Sadler
Delegate:	Not appointed

9 **Columbia Historical Society (1899)**

President:	Hemer T. Rosenberger, 1307 New Hampshire Ave., N.W., Washington, D.C. 20036
Vice-President:	Wilcomb E. Washburn, Smithsonian Institution, Washington, D.C. 20560
Secretary:	Edward F. Gerber, 1233 30th St., N.W., Washington, D.C. 20007
Delegate:	Paul H. Oehser, National Geographic Society, Washington, D.C. 20036

10 **Botanical Society of Washington (1902)**

President:	Peter M. Mazzeo, U.S. National Arboretum, 28th & M Sts., N.E., Washington, D.C. 20002
Vice-President:	Laurence E. Skog, Smithsonian Institution, Dept. of Botany, Washington, D.C. 20560
Secretary:	Erik A. Neumann, U.S. National Arboretum, 28th & M Sts., N.W., Washington, D.C. 20002
Delegate:	Conrad B. Link, Univ. of Md., Dept. of Horticulture, College Park, Md. 20742

11 **Society of American Foresters, Washington, Section (1904)**

President:	Thomas B. Glazebrook, 7809 Bristow Dr., Annandale, Va. 22003
President-elect:	Arthur H. Smith, 3301 Wessynton Way, Alexandria, Va. 22309
Secretary:	George Cheek, American Forest Institute, 1619 Mass. Ave., N.W., Washington, D.C. 20036
Delegate:	T. B. Glazebrook

12 **Washington Society of Engineers (1907)**

President:	Joseph H. Seelinger, 5367 28th St., N.W., Washington, D.C. 20015
Vice-President:	Dean Harold Liebowitz, Sch. of Engineering, George Washington Univ., Washington, D.C. 20052
Secretary:	Guy S. Hammer, II, 1526 17th St., N.W., #107, Washington, D.C. 20036
Delegate:	George Abraham, 3107 Westover Dr., S.E., Washington, D.C. 20020

13 **Institute of Electrical & Electronics Engineers, Washington Section (1912)**

Chairman:	Alvin Reiner, 11243 Bybee St., Silver Spring, Md. 20902
Vice-Chairman:	Dennis Bodson, 233 North Columbus St., Arlington, Va. 22203
Secretary:	C. David Crandall, 12214 Old Colony Dr., Upper Marlboro, Md. 20870
Delegate:	George Abraham, 3107 Westover Dr., S.E., Washington, D.C. 20020

14 **American Society of Mechanical Engineers, Washington Section (1923)**

Chairman:	Darnley Howard, Postal Service Research Institute, Rockville, Md.
Vice-Chairman:	Michael Chi, 2721 24th St. N., Arlington, Va. 22207
Secretary:	Robert L. Hershey, Booz-Allen Applied Res., Bethesda, Md. 20014
Delegate:	Michael Chi

15 **Helminthological Society of Washington (1923)**

President:	Robert S. Isenstein, Animal Parasitology Inst., BARC-East, Beltsville, Md. 20705
Vice-President:	A. Morgan Golden, Nematology Lab., Plant Protection Inst., BARC-West, Beltsville, Md. 20705
Secretary:	William R. Nickle, Nematology Lab., Plant Protection Inst., BARC-West, Beltsville, Md. 20705
Delegate:	James H. Turner, Division of Res. Grants, NIH, Westwood Bldg., Rm. A25, Bethesda, Md. 20014

16 **American Society for Microbiology, Washington Branch (1923)**

President:	Joseph C. Olson, Jr., Food & Drug Adm., Washington, D.C.
Vice-President:	Charles H. Zierdt, NIH, Bethesda, Md. 20014
Secretary:	June W. Bradlaw, Food & Drug Adm., Washington, D.C.
Delegate:	None appointed

17 **Society of American Military Engineers, Washington Post (1927)**

President:	Lt. Col. Elton D. Scheideman, HQ USAF/P REN, Washington, D.C. 20330
Vice-President:	Capt. Clayman C. Meyers, OICC Bethesda, 200 Stovall St., Naval Facilities Engrg. Command, Alexandria, Va. 22332
Secretary:	Capt. Terry M. Fenstad, HQ USAF/PREV, Washington, D.C. 20330
Delegate:	Hal P. Demuth, 4025 Pine Brook Rd., Alexandria, Va. 22310

18 **American Society of Civil Engineers, National Capital Section (1942)**

President:	L. Gary Byrd, 2921 Telester Ct., Falls Church, Va. 22042
Vice-President:	James W. Harland, 1511 K St., N.W., Suite 337, Washington, D.C. 20005
Secretary:	John J. Duffy, American Concrete Pipe Assoc., 8320 Old Court House Rd., Vienna, Va. 22180
Delegate:	Shou-shan Fan, 2313 Glenallen Ave., #202, Silver Spring, Md. 20906

19 **Society for Experimental Biology & Medicine, D.C. Section (1952)**

President:	Juan C. Penhos, Dept. of Physiology & Biophysics, Georgetown Univ. School of Med. & Dentistry, Washington, D.C. 20007
President-elect:	Cyrus R. Creveling, 4516 Amherst Lane, Bethesda, Md. 20014
Secretary:	Marvin Bleiberg, 3613 Old Post Rd., Fairfax, Va. 22030
Delegate:	Donald F. Flick, 930 19th St., So., Arlington, Va. 22202

20 **American Society for Metals, Washington Chapter (1953)**

Chairman:	Klaus M. Zwilsky, U.S. Atomic Energy Comm., Washington, D.C. 20545
Vice-chairman:	Alan H. Rosenstein, Air Force Office of Scientific Res., 1400 Wilson Blvd., Arlington, Va. 22209
Secretary:	Joseph Malz, NASA, Code RWM, Washington, D.C. 20546
Delegate:	Glen W. Wensch, U.S. Atomic Energy Comm., Washington, D.C. 20545

21 **International Association for Dental Research, Washington Section (1953)**

President:	Robert W. Longton, Dental Sciences Dept., Naval Med. Res. Inst., NNMC, Bethesda, Md. 20014
Vice-President:	Nelson W. Rupp, Dental Res., NBS, Washington, D.C. 20234
Secretary:	Donald W. Turner, Dental Sciences Dept., Naval Med. Res. Inst., NNMC, Bethesda, Md. 20014
Delegate:	William V. Loebenstein, 8501 Sundale Dr., Silver Spring, Md. 20910

22 **American Institute of Aeronautics and Astronautics, National Capital Section (1953)**

President:	Philip R. Compton, 6303 Mori St., McLean, Va. 22101
Vice-President:	Jack Suddreth, Code RLC/Aero. Prop. Div., NASA Headquarters, Washington, D.C. 20546
Secretary:	Paul M. Burris, The Boeing Co., 955 L'Enfant Plaza North, S.W., Washington, D.C. 20024
Delegate:	Frank J. Ross, Deputy for Rqmts., Off. Asst. Sec. of A.F., The Pentagon, Rm. 4E973, Washington, D.C. 20330

23 **American Meteorological Society, D.C. Chapter (1954)**

Chairman:	G. Stanley Doore, NOAA/NWS/TPB/WIIIX2, 1302 Gramax Bldg., 8060 13th St., Silver Spring, Md. 20910
Vice-Chairman:	Robert Ellingson, IFDAM, Space Services Bldg., Univ. of Md., College Park, Md. 20742
Secretary:	H. Michael Magil, NOAA/NWS/PSB/WII2X3, 1425 Gramax Bldg., 8060 13th St., Silver Spring, Md. 20910
Delegate:	A. James Wagner, NOAA/NWS/NMC W31, 604 World Weather Bldg., 5200 Auth Rd., Washington, D.C. 20233

24 **Insecticide Society of Washington (1959)**

President:	Richard Back, Union Carbide, 1730 Pa. Ave., N.E., Suite 1250, Washington, D.C. 20006
President-elect:	John W. Kennedy, APHIS, USDA, Hyattsville, Md.
Secretary:	John Neal, ARS, ARC, Bldg. 467, Beltsville, Md. 20705
Delegate:	Robert Argauer, ARS, ARC, Bldg. 309, Beltsville, Md. 20705

25 **Acoustical Society of America (1959)**

Chairman:	John A. Molino, Sound Section, NBS, Washington, D.C. 20234
Vice-chairman:	Charles T. Molloy, 2400 Claremont Dr., Falls Church, Va. 22043
Secretary:	William K. Blake, Naval Ship R & D Ctr., Bethesda, Md. 20034
Delegate:	None appointed

26 **American Nuclear Society, Washington Section (1960)**

President:	Andre Gage, Potomac Electric Power Co., 1900 Penn. Ave., N.W., Washington, D.C.
Vice-President:	B. E. Leonard, Institute for Resource Management, 4948 St. Elmo Ave. Bethesda, Md. 20014
Secretary:	S. Bassett, NUS Corp., Rockville, Md. 20852
Delegate:	Dick Duffy, Nuclear Engineering, Univ. of Md., College Park, Md. 20742

27 **Institute of Food Technologists, Washington Section (1961)**

Chairman:	Tannous Khalil, Giant Foods, Inc., Landover, Md. 20785
Vice-chairman:	Florian C. Majorack, Food & Drug Adm., Washington, D.C.
Secretary:	Glenn V. Brauner, National Canners Assoc., Washington, D.C. 20036
Delegate:	William Sulzbacher, 8527 Clarkson Dr., Fulton, Md. 20759

28 **American Ceramic Society, Baltimore-Washington Section (1962)**

Chairman:	W. T. Bakker, General Refractories Co., P.O. Box 1673, Md. 21203
Chairman-elect:	L. Biller, Glidden-Dirkee Div., SCM Corp., 3901 Hawkins Point Rd., Baltimore, Md. 21226
Secretary:	Edwin E. Childs, J. E. Baker Co., 232 E. Market St., York, Pa. 17405
Delegate:	None appointed

29 **Electrochemical Society, National Capital Section (1963)**

Chairman:	Judith Ambrus, Naval Surface Weapons Ctr., White Oak, Md. 20910
Vice-chairman:	John B. O'Sullivan, 7724 Glenister Dr., Springfield, Va. 22152
Secretary:	John Ambrose, NBS, Washington, D.C. 20234
Delegate:	None appointed

30 **Washington History of Science Club (1965)**

Chairman:	Richard G.Hewlett, Atomic Energy Comm.
Vice-chairman:	Deborah Warner, Smithsonian Institution
Secretary:	Dean C. Allard
Delegate:	None appointed

31 **American Association of Physics Teachers, Chesapeake Section (1965)**

President:	William Logan, D.C. Teachers College, 2565 Georgia Ave., Washington, D.C. 20001
Vice-President:	Eugenie V. Mielczarek, George Mason Univ., 4400 University Dr., Fairfax, Va. 22030
Secretary:	John B. Newman, Towson State College, Towson, Md. 21204
Delegate:	Bernard B. Watson, 6108 London Lane, Bethesda, Md. 20034

32 **Optical Society of America, National Capital Section (1966)**

President:	James B. Heaney, NASA, Goddard Space Flight Ctr., Greenbelt, Md. 20770
Vice-President:	Diane Prinz, Naval Research Lab., Washington, D.C. 20375
Secretary:	Marilyn J. Dodge, National Bureau of Standards, A-251, Physics Bldg., Washington, D.C. 20234
Delegate:	James B. Heaney

33 **American Society of Plant Physiologists, Washington Section (1966)**

President:	Aref Abdul-Baki, USDA, ARCW, Beltsville, Md. 20705
Vice-President:	Dale G. Blevins, Dept. of Botany, Univ. of Md., College Park, Md. 20742
Secretary:	Anne H. Datko, NIMH Bldg. 32A, Rm. 101, Bethesda, Md. 20014
Delegate:	W. Shropshire, Jr., Smithsonian Institution, 12441 Parklawn Dr., Rockville, Md. 20852

34 **Washington Operations Research Council (1966)**

President:	Frank T. Trippi, 5809 Clermont Dr., Alexandria, Va. 22310
President-elect:	Craig C. Sherbrooke, 8513 Kingsgate Rd., Potomac, Md. 20854
Secretary:	Neal D. Glassman, 1 Paddock Ct., Potomac, Md. 20854
Delegate:	John G. Honig, 7701 Glenmore Spring Way, Bethesda, Md. 20034

35 **Instrument Society of America, Washington Section (1967)**

President:	Francis C. Quinn
President-elect:	John I. Peterson
Secretary:	Frank L. Carou
Delegate:	None appointed

36 **American Institute of Mining, Metallurgical & Petroleum Engineers (1968)**

Chairman:	Phil W. Guild, U.S. Geological Survey, Natl. Ctr., Mail Stop 952, 12201 Sunrise Valley Dr., Reston, Va. 22092
Vice-Chairman:	Gus H. Goudarzi, U.S. Geological Survey, Natl. Ctr., Mail Stop 920, 12201 Sunrise Valley Dr., Reston, Va. 22092
Secretary:	John Patterson, Energy Res. & Dev. Adm., Washington, D.C. 20545
Delegate:	Carl H. Cotterill, Bureau of Mines, U.S. Dept. of the Interior, 2401 E St., N.W., Washington, D.C. 20241

37 **National Capital Astronomers (1969)**

President:	Benson J. Simon
Vice-President:	Geoffrey P. Hornseth
Secretary:	William R. Winkler
Delegate:	None appointed

38 **Maryland-District of Columbia and Virginia Section of Mathematical Assoc. of America (1971)**

Chairman:	Geraldine A. Coon, Goucher College, Baltimore, Md.
Secretary:	John Smith, George Mason University, Fairfax, Va.
Delegate:	Patrick Hayes, 5565 Columbia Pike #812, Arlington, Va 22204

39 **D.C. Institute of Chemists (1973)**

President:	Kelso B. Morris, 1448 Leegate Rd., N.W., Washington, D.C. 20012
President-elect:	Leo Schubert, 8521 Beech Tree Rd., Bethesda, Md. 20034
Secretary:	Fred D. Ordway, 2816 Fall Jax Dr., Falls Church, Va. 22042
Delegate:	Miloslav Rechcigl, Jr., 1703 Mark Lane, Rockville, Md. 20852

40 **The D.C. Psychological Association (1975)**

President:	Lee Gurel, 2723 Woodley Pl., N.W., Washington, D.C. 20008
President-elect:	Richard P. Youniss, 6111 43rd Ave., Hyattsville, Md. 20781
Secretary:	Eugene Stammeyer, 419 Timber Branch Parkway, Alexandria, Va. 22302
Delegate:	John J. O'Hare, 301 G St., S.W., #824, Washington, D.C. 20024

41 **The Washington Paint Technical Group (1976)**

President:	Rufus F. Wint, Hercules, Inc., 910 Market St., Wilmington, Delaware 19899
Vice-President:	William Georgov, J. M. Huber Corp., P.O. Box 310, Havre de Grace, Md. 21078
Secretary:	Robert F.Brady, Jr., General Services Adm. (FMBP), Washington, D.C. 20406
Delegate:	Paul G. Campbell, National Bureau of Standards, B-348 Br., Washington, D.C. 20234

M = Member; F = Fellow; E = Emeritus member L = Life Fellow. Numbers in parentheses refer to numerical code in foregoing list of affiliated societies.

A

ABELSON, PHILIP H., Ph.D., Carnegie Inst. of Washington, Carnegie Institution of Washington, 1530 P St., N.W., Washington D.C. 20005 (F-1, 4, 7, 16)
ABRAHAM, GEORGE, M.S., Ph.D., 3107 Westover Dr., S.E., Washington, D.C. 20020 (F-1, 6, 12, 13, 31, 32)
ACHTER, M. R., Code 6416, U.S. Naval Research Lab., Washington, D.C. 20375 (F-20, 36)
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B

BAKER, ARTHUR A., Ph.D., 5201 Westwood Dr., N.W., Washington, D.C. 20016 (E-7)
BAKER, LOUIS C.W., Ph.D., Dept of Chemistry, Georgetown University, N.W., Washington, D.C. 20007 (F-4)
BALLARD, LOWELL D., 722 So. Colonial, Sterling, Va. 22170 (F-1, 6, 13, 32)
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WANTED

Women Chemists

NATIONAL SCIENCE FOUNDATION PROGRAM

The National Science Foundation in an attempt to tap the underutilized resource which women represent has funded a series of projects under their Women in Science Program, whose objective is to develop and test methods to attract and retain women in scientific careers.

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The American University Program will be a twenty-eight week program beginning October 5, 1976 and ending May 13, 1977. The program will meet five days a week Monday through Friday from 10:00 a.m. until 2:00 p.m. and will normally be one hour of lecture and three hours of laboratory per day.

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Women in Science Program
Department of Chemistry
The American University
Washington, D. C. 20016

WOMEN IN CHEMISTRY PROGRAM

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JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES

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Alternatives for Biological Resources in Africa[1]

Edward S. Ayensu

Director, Endangered Species Program, National Museum of Natural History,

ABSTRACT

This paper calls attention to the fact that most of the current basic food items that feature in the diets of African homes were historically recent introductions to that continent. Attention is directed to the need for the development of the underexploited plants and animals that seem to have economic potential. The local sources of plant and animal proteins including fish proteins are discussed. Observations are made on the changing food habits of the people on the African continent. The need for substantial research in the biological resources of the continent are discussed.

Over the years I have become painfully aware of the fact that we in Africa have been making very little use of the biological resources available on our continent. In fact, the current use of only a few of the many biological resources with which Africa is endowed is a reflection of our inactivity in exploring the new and alternative resources of this magnificent part of the world. I would venture to say that since the Neolithic practically no new major food item emanating from the African flora has been added to the diet of the people.

I had the good fortune of being appointed the Co-Chairman of the U. S. Academy of Science's panel on "Underexploited Tropical Plants of Promising Economic Value" in March 1974. The work of the panel culminated in the gathering of an unbelievable amount of information on the many plants that people in the third world have not been using to their best advantage. The panel was charged with three main objectives: to identify neglected but seemingly useful tropical plants, both wild and domesticated, that have economic potential; to select the plants that showed the most promise for wider exploitation throughout the tropics; and to indicate the requirements and avenues for research that will ensure that selected plants reach their fullest potential.

I offer these same objectives to African scientists as a basis for seeking alternatives for the judicious exploitation of our biological resources.

Of the approximately 40,000 species of plants that occur in Africa, only a small number have been used throughout human history. Furthermore, of the handful of crops that form the bulk staples, a significant portion consists of plants that are not native to Africa. For example, the tropical root crop cassava (*Manihot esculenta*), an important carbohydrate source in the diet of many African people today, is a native of Brazil, from whence it spread to other

[1] Paper presented at the Seminar for African Alternatives at the National Assembly, Senegal, from 4–6 February 1976.

parts of Latin America and the rest of the tropical areas of the world. The groundnut (*Arachis hypogaea*), which is rich in non-drying oil and protein as well as vitamins B and E, is also a native of South America. It was the Portuguese who introduced the plant from Brazil to West Africa in the 16th Century. The sweet potato (*Ipomoea batatas*), with its edible tubers and tender leaves, is likewise a native of tropical America. Ethnobotanical records show that the sweet potato was grown in Mexico and many parts of Central and South America during pre-Columbian times but was unknown in Africa, Asia, and Europe during the same period. The cocoyam (*Zanthosoma sagittifolium*) is a native of tropical America. Although the Portuguese and the Spanish had known about this plant, it was not until 1841 that missionaries from the West Indies introduced it to Ghana. Rice (*Oryza sativa*), which plays a very important role in the diet of Africa, traces its origin to southeast Asia. Once again it was the Portuguese who introduced rice into Brazil and West Africa. Maize (*Zea mays*) is undoubtedly one of the most important cereals in the African diet today. Like most of the above-mentioned cultivated plants, maize is not native to Africa. The plant was in cultivation in the New World during pre-Columbian times. Maize in its present form has never been found growing in a wild state anywhere. There is very reliable evidence that maize did not reach the Old World (including Africa) before 1492.

Of the commercially) important cash crops that are grown in Africa, cocoa (*Theobroma cacao*) is perhaps the most important—certainly for Ghana, Nigeria and the Ivory Coast. I hope you will not be too surprised to learn that, again, the cocoa tree is a native of tropical South America. The plant was introduced to the islands in the Gulf of Guinea in the 17th Century by the Spanish and Portuguese. A few cocoa pods of the Amelonado variety were taken to Ghana in 1879 from Fernando Po and, as you are all aware, these few pods gave rise to a very important industry in a major portion of West Africa. Another cash crop that features prominently in the industrial activity of some African countries is para rubber (*Hevea brasiliensis*). As its scientific name suggests, this plant originated in the tropical rain forests of the Amazon basin in South America.

I could go on and on citing examples of a number of other crops that are currently used in Africa but have their origins elsewhere. I do not want to leave you with the impression that Africa has not contributed something to other countries. For example, sorghum, which is of African origin, was introduced to China early in human history. This crop is now widely distributed in China because of the development of several local varieties. Nevertheless it is a sobering feeling to visualize what our dietary situation might have been on this continent if all the foreign crops I have mentioned were not available to us today. I feel uncomfortable even to think of the striking readjustments in our lives that would be necessary if we had not been exposed to all these introductions.

Why is it that throughout our history we have made but little use of our biological resources? The answer to this loaded question should be viewed from an historical perspective. During the colonial era very little attention was given to scientific research on the many indigenous plant and animal species that may be of promising economic value, because the consumer demands of the metropolitan countries of Europe were the principal determinants of the agrarian practices encouraged in the colonies. The scientific research institutes that were established in a number of African countries during the colonial era were slanted to fulfill specific missions. For example, many of the research organisations established by the British and the French in West Africa were mainly concerned with problems connected with the production of raw materials for export to the colonial and other European and North American markets. As I pointed out during my presentation to the West

African Science Association Conference here in Dakar some two years ago, the research efforts of the science institutes in Africa have not changed materially since the attainment of independence. The same mentality that guided research activities in Africa before political independence is being perpetuated today. Furthermore, several food items that were featured in the diets of Africans before the coming of the Europeans have been discarded gradually and replaced by kinds of foods that are readily acceptable to Europeans. It is only in relatively recent years that Africans have become proud to present indigenous dishes to their foreign visitors.

Apart from the colonial influence on agricultural research priorities in Africa, there is a fundamental attitude towards agriculture that separates, for example, the American Indian farmer from the African farmer. Historically the Central and South Americans of Mexico and Peru (to mention but two countries) were more interested in developing different strains of crops while their African counterparts were interested in the domestication of animals. And, as African civilization progressed, animals often became the equivalent of money, e.g. cattle culture in Rwanda.

Another limiting factor in the proper exploitation of our plant resources has been the quality of African soils. By and large, the soils of Africa are poor. You are all familiar with the typical weathering processes of our soils that often result in the formation of hard, reddish clay soils commonly known as laterite. Lateritic soils develop when the fertile topsoil is eroded away by the intensive rainstorms that expose the red clay soils underneath to the high solar radiation that often follows a big downpour of rain in the tropics. In the arid regions of Africa, wind erosion results in the removal of the fertile topsoil and renders the land unsuitable for efficient agricultural use. Over-grazing in certain parts of Africa has resulted in more serious abuse of the land than have other causes of soil erosion. The browsing habits of goats, for example, are very familiar to many of you. Until marked soil conservation measures are taken to safeguard the land, we cannot begin to think seriously about the efficient use of the limited suitable farmlands that are still available in Africa.

I think it is very important for us to understand that soil biology is a crucial component in the assessment of our biological resources because it is the basis of virtually all plant life, and hence all faunal elements depend on it as well. In a sense the soil is the most important biological medium since its composition includes both organic and inorganic substances. I need not remind you that our lack of knowledge of tropical soil was the principal reason for the Groundnut Scheme failure. It is, therefore, important that throughout our assessment of the biological resources of Africa, we bear in mind the state of our soils.

Plant Protein Production

When I began to reflect on the alternatives for biological resources in Africa, my mind immediately centered around the problems of protein production for food. Of all the possible sources for protein, I consider plants the most important. Plant proteins are basically cheaper than animal proteins. Let us first consider edible leaves of tropical origin. Proteins are first created in leaves. The process of photosynthesis is principally responsible for the creation of many intermediate reactions such as the production of keto acids. Briefly, soluble nitrogenous compounds and minerals are brought to the leaves where the ammonia portion is combined directly with the keto acids to form amino acids, which lead to the process of building-up of protein aggregates. From the standpoint of nutrition, there is no excuse for the diet of the African people to be short of proteins, because edible green leaves are abundant on the continent. The green leaves are rich in proteins but, in addition, they are physiologically important as regulators of the digestive tract. The green leaves also contain important vitamin and mineral components that offer further enrichment to diets that are basically starch-based. Vitamin A is often found in large quantities in dark green leaves and is often resistant to the effects of cooking. Vitamin C, which is also present in leaves in appreciable quantities, often tends to be destroyed by cooking. Vitamin B, which is soluble in water, tends to be lost when cooking water is discarded. Other ingredients such as riboflavin and thiamine occur in reasonable quantities in leaves.

If I may digress a moment, just before I visited the People's Republic of China in July 1975, I was invited to dinner by the Chinese Ambassador in Ghana. At dinner several delicious dishes were served, including a wide assortment of green vegetables. The delectable qualities of the greens were so distinctive that I naturally paid the Ambassador a special compliment on them. The Ambassador quickly made the point that the green vegetables were all from Ghana. I was somewhat embarassed because I became distinctly aware of the lack of imagination that has surrounded our use of the vegetables that are readily available. I hasten to add that throughout my travels in Africa and other parts of the world, I have encountered a number of plant species whose leaves are accepted as edible. My plea is that a number of these green-leafed plants may be high protein sources, and therefore it is our responsibility as research scientists to investigate these plants for their nutritional importance both for human food and for animal feed.

In addition to the native plants that should be reviewed for their possible use, there are some important tropical plants that can be introduced to Africa which could assume the importance that, for example, maize, rice, cassava and groundnuts have achieved. The winged bean (*Psophocarpus tetragonolobus*) is a legume of far-eastern tropical origin with tremendous nutritional possibilities. In the recent report "Underexploited Tropical Plants with Promising Economic Value," it was described as follows: "The winged bean is a tropical legume with a multitude of exceptionally large nitrogen-fixing nodules. It produces seeds, pods, and leaves (all edible by humans and livestock) with unusually high protein levels; tuberous roots with exceptional amounts of protein; and an edible seed oil."

The winged bean has important potential for small-scale farmers. It is a fast-growing perennial that is particularly valuable because it grows in the wet tropics where protein deficiency in human diets is not only great but difficult to remedy. Winged bean seeds rival soya beans (*Glycine soja*) in oil and protein content, and the plant has the added advantages of protein-rich roots and edible foliage.

Though relatively unknown, this multipurpose legume appears to meet many dietary needs of the tropics.

I can forsee this legume assuming the same importance as soya beans in the very near future. After all, it was only fifty years ago that the soya bean became a prominent Asian crop, especially in China and Japan. Today, because of intensive agronomic research on the soya bean, it has become one of the principal crop plants in the world. When I visited Sri Lanka in June 1975 as a member of the U. S. Academy of Science's team that participated in a workshop on "Natural Products for Sri Lanka's Future," I discovered that the tender pods of the winged bean plant are delicious and heavily consumed in that country. The flowers, leaves, and shoots are eaten as vegetables. The stem of the plant serves as animal feed. Some varieties of this plant produce a fleshy tuber similar to the potato. It tastes very much like potato, and it contains 20% more protein. Its protein content is therefore 20 times that of cassava and certainly 10 times more than yams and other edible root crops.

I am delighted to inform you that to my knowledge the Agricultural Research Station of the University of Ghana and the International Institute of Tropical Agriculture in Nigeria are already doing some work on this highly promising plant.

In addition to looking for new crop plants, it is essential that we do not lose sight of the limited uses to which we are currently putting the existing crops that feature in our diets. For example, a substantial portion of the cassava harvest in Africa is eaten boiled, roasted, or in the form of Gari. A certain amount of bulk cassava is used in preparing tapioca and starch. The potential for world market uses for cassava products is substantial. Apart from growing cassava for human consumption, two major markets have not been exploited to the fullest. The industrial starch market is still open. People often forget that cassava starch has found application in the manufacture of foodstuffs, textiles, and adhesives for stamps and envelopes, as well as newsprint, cardboard, gelling agents, fillings and munitions. The major markets for industrial starch include Japan, the United States and Canada. Because of the erratic supply of cassava starch from many developing countries (and this includes those in South America) the developed countries have been using only a small percentage of cassava starch in their manufacturing industries. If we can prove to prospective buyers that we are able to supply this needed raw material on a sustained basis and at competitive prices, I have no doubt that we can be assured of handsome financial returns.

The other use for cassava requires substantial quantities of pellets for the animal feed market. Several European countries are now using large quantities of cassava as a cheap source of carbohydrate for livestock. Many livestock production concerns have realised that it is relatively cheaper to prepare feed from cassava and soya beans than to use cereals. In fact it has been shown that an equal mix of cassava and soya beans is a feed superior to an equal mix of soya beans and maize. To my knowledge, Thailand is shipping large quantities of cassava chips to Europe. Obviously, because of our proximity to Europe and because of the large amount of marginal land available to grow cassava, the West African countries can develop a substantial market for this product.

Several other plants of tropical origin have been identified in the report on "Underexploited Tropical Plants of Promising Economic Value." I urge you all to take a look at the report and make use of as many of the recommended plants as possible.

Plants Containing Special Qualities

The exploitation of our biological resources should not be confined to only those plants and animals that feature in our daily diet. Some plants can indeed be exploited in external markets for sorely needed foreign exchange. In recent years it became obvious that the cyclamates used as a sweetening agent in a number of baby foods as well as soft drinks have some deleterious effects on man. It, therefore, became necessary to seek a sweetening substitute. After much experimentation in the United States and Europe, special interest was centered on the Miracle Berry (*Synsepalum dulcificum*), a West African plant. The pulp of its fruit obscures the sour taste of various food substances. As I pointed out in an earlier publication, Ghanian children often show great delight in impressing their friends that they can consume sour fruits such as lemon, lime, and grapefruit without expressing any distaste. This plant soon became a subject of intensive research in a number of American and European laboratories. The amino acid composition of the protein of this berry was soon worked out. The active principle of the berry was found to be a glycoprotein with a molecular weight of about 44,000. Soon after the labile glycoprotein was stabilized, and this enabled its use in a pill form as a sweetening agent. I must add that its use has not been confined to sweetening ordinary foods and drinks; it has also been used as a sweetener for diabetics. Imaginative individuals in America and in Europe have taken advantage of the natural chemical properties of the berry only to enjoy vaginal secretions that change in taste from sour to sweet as part of their sexual amusement. The pills manufactured from this plant are known as the "Miracle Fruit Drops." The Miracle Berry plant is an economically important biological resource that should be exploited further. The plant grows in the wild in West Africa. It could easily be brought into cultivation and the harvest exported to pharmaceutical companies that manufacture the pills.

Medicinal Plants

Historically, plant-derived drugs have featured prominently in the treatment of all kinds of disease in Africa. The administration of the drugs has been in the hands of native herbalists. Plant species have been variously used to arrest convulsions, stop natural habitual abortions, cure syphilis, suppress chronic ulcers, remove warts on the sole of the foot, de-worm the afflicted, arrest asthma, serve as mosquito repellent, induce the flow of breast milk, etc. Over the years I have accumulated information on the uses of over 200 plant species from Ghana alone. No doubt several impressive lists could be obtained for other African countries.

Throughout the world today there is a serious shortage of supply of plant-derived drugs. Several of the drug-producing plants available in Africa can be developed into the basis of a highly sophisticated natural products industry. Some of the plants could be cultivated for the manfacture of end-product drugs or processed to yield compounds that, on chemical modification, can yield additional drugs. In some cases extractions could be made for use as primary starting material for the synthesis of several drugs. My own studies of yams (*Dioscorea* sp.) over the years have shown that the active principle diosgenin is not a useful drug by itself, but it is a starting material for the synthesis of most of the oral contraceptives on the market today. In recent years the plant *Fagara xanthoxyloides* has become a very important material in the cancer research programs in the United States. Other plants such as *Griffonia simplicifolia*, *Fagara macrophylla* and *Rauwolfia vomitoria* are being collected from the wild in large quantities for shipment abroad. The financial possibilities are endless. I will only remind you that, for example, in 1974 the United States of America produced great quantities of drugs derived directly from plants and sold them to the consumer to the tune of three billion dollars. This figure does not include the sales of antibiotics. I wish to emphasize again that a carefully planned screening program of the drug-producing plants will yield fantastic financial results for Africa.

Animal Protein Production

Throughout the history of Africa, the utilization of wildlife as a major source of meat protein has been significant. However, traditional hunting practice has led to a decrease in the populations of some of the choice game meats. In Ghana, for example, meat of the grasscutter (*Thryonomys swinderianus*) seems to get more and more expensive in the local open markets even if its availability seems to be quite normal. In fact, it has been observed that the more the supply of the grasscutter meat in the city markets, the higher the price. This observation simply means that the supply of this particular bushmeat is not meeting consumer demand.

There are several species of game animals that have proven to be good protein sources. In East Africa game animals such as the eland, impala, zebra, wildebeest, giraffe, duiker, warthog, steenbuck, waterbuck, buffalo, bush pig, elephant and kudu feature daily in the diets of many people. One of the game reserves I am familiar with is the Mole National Park in Ghana. The game animals I encountered there include hartebeest, buffalo, waterbuck, roan antelope, kob, bushbuck, oribi, duiker, warthog, baboon, patas monkey and green monkey. All these animals constitute substantial sources of protein if their numbers are allowed to swell and then cropped. Unfortunately, very few systematic attempts have been made to establish game ranches in order to maximize their production. From the few studies that have compared cattle and game animals, it is evident that the production of game animals generally outstrips that of cattle on all counts, especially if we take into consideration the marginal status of the available land and the carrying capacities of the various habitats for the two groups of animals. It is now a well-known fact that the effects of domesticated game animal grazing pressure on natural vegetation are less harmful than those of cattle and certainly more favorable than those of goats. Several detailed studies conducted on game ranches in East and South Africa have demonstrated that game animals can be supported without damage to grass cover and without any serious destruction of the soil. On the other hand, lands used for cattle ranching are almost invariably rendered useless because of the serious damage to the soil and vegetation. Different species of game animals graze and browse on different plant species within a habitat. Hence the presence of a variety of different game animals within one particular vegetation-type should not give cause for much concern. In a recent study conducted in the Serengeti-Mara Game Reserves, it has been shown that the two most abundant grazers in the reserves, the wildebeest and the Thomson's gazelle, manage to co-exist instead of competing for food. The wildebeest is a heavy grazer, and as it migrates across the Serengeti Plains it somehow stimulates the growth of the plant species that are exploited by the gazelle in the dry season. This clearly shows a co-existence between two heavy grazers which depend upon the same habitat for their survival.

Another important factor to consider is the fact that the total biomass of game animals living on low quality land is about equal the total biomass of cattle on a much better quality land. Furthermore, and perhaps most important, is the quality of protein produced by game animals as against that produced by cattle. Various studies on the nutritional value of bushmeat have shown that the quality of protein is at least as high as that of cattle. In addition, the vitamin content of bushmeat is much higher than that of beef, mutton, or pork.

Another advantage in favour of game animals, as a source of protein, is that less food energy is needed to bring their weight up before cropping. The amount of grain used in feeding cattle, sheep and pigs before they are slaughtered is being questioned by energy conservation minded persons all over the world today. It is, therefore, important that we seriously consider the feeding requirements of the conventional domesticated animals as against the natural feeding habits of game animals.

There is no doubt that the demand for bushmeat is increasing in many parts of Africa. It is, therefore, necessary that proper investments are made to infuse sophisticated management into game ranches so that those establishments can be self-sustaining and yet produce a greater quantity of protein.

As I intimated earlier, East and South Africa have had more experience in game ranching than has West Africa. In Botswana, for example, a number of game farms manage wildlife along with cattle on a sustained-yield basis. The Galana Game Ranch Research Project in Kenya was started in 1970 to explore the best methods for exploiting domesticated game. One of the Project's activities is the management of both game and conventional livestock under identical ranching conditions. In a screening programme, game animals such as the fringe-eared oryx, eland, buffalo, ostrich, and the Peters' race of Grant's gazelle have been herded with Boran cattle, small East African goats and crossbred Dorper, Masai, and Merino sheep. I have no doubt that this project is going to be successful in view of the quality of the scientific manpower and institutions involved in the entire programme.

I also have learned that a proposed Nazinga Game Ranch Project for Upper Volta is being planned at the moment by the African Wildlife Husbandry Development Association of Canada and various agencies of the Upper Volta Government. If this project becomes a reality it will be the first well-planned game ranching project for West Africa. The practical information that will be derived from the proposed project undoubtedly will be of tremendous benefit to other West African countries contemplating similar projects.

In addition to bushmeat production, properly managed industries can be developed to handle the production of processed animal skins and trophies for sale. It seems logical that we can combine game ranching and sport hunting in our quest to seek substantial alternatives for the biological resources of Africa.

Fish Protein Production

No discussion of the biological resources of Africa can be complete without careful consideration of the fish fauna of the continent. We are all aware that fish is abundantly rich in high quality protein in addition to fat, minerals and vitamins. It is well known also that the nutritive value of fish is, in many cases, superior to that of beef and that it also is readily digestible and not easily denatured by cooking. For centuries our fishermen have exploited both marine and fresh waters. Based on earlier figures, I estimate that nearly 3.5 million metric tons of fish are currently harvested annually in Africa. Unfortunately, a substantial proportion of the catch is spoiled because of the lack of refrigeration facilities in most homes. Furthermore, because of the fish preferences of our people, several perfectly nutritious species of fish are not eaten. It seems obvious that with current techniques available in Africa, many of the unpopular fish, as well as the large quantities of perfectly desirable fish that are lost by spoilage, can be used in preparing fish protein concentrates for direct consumption by humans as well as in the preparation of fish meal for cattle and poultry feed.

In recent years a number of our coastal countries have been engaging in deep-sea fishing on a commercial basis. While on a recent visit to Japan, I was gratified to eat some prawns and shrimp that were of West African origin. However, certain foreign fishing fleets have been invading the territorial waters of Africa to the extent that if international agreements are not concluded soon most of the choice fish will be overexploited before Africa is ready to embark on a full-scale fishing industry.

In the case of fresh-water or inland fishing practices, many changes are necessary. In most cases, the fishing techniques of the Neolithic have not been improved upon. In areas where fishing techniques have improved, very little study has gone into the assessment of the fish populations in rivers, lagoons and lakes. As a result of our lack of knowledge of the breeding systems of the various species of fish in African inland waters, certain fish populations are being overly exploited. In a number of cases we do not know the species composition of many of the inland waters on the continent. I need not emphasize that a number of the natural and man-made lakes in Africa have tremendous potential for the production of fish protein if proper management principles are followed. Most of us are familiar with the importance of species of *Tilapia* in the diet of many peoples of East and West Africa. Unfortunately, our enthusiasm for eating this delicious fish has not been matched by our desire to study in detail all aspects of the biology of this fish, particularly its adaptation to pond culture. It is essential that if we want to derive maximum financial benefit from our fish resources, we must encourage systematic scientific research in all areas of fish biology.

Changing Food Habits

Seeking alternative biological resources for food, especially for home consumption, presupposes that the dietary habits of our people are not static, but are dynamic. Every society's food habits are governed to some extent by customs, traditions, and cultural beliefs. In some societies the taboos against certain foodstuffs are so rigid that even in the case of acute famine, the overly zealous would rather die than eat "forbidden" foods. Fortunately, most African societies are more flexible and capable of practical considerations in their eating habits than some of their Asian counterparts.

As I have indicated earlier, most of the major food items that feature constantly in our diets have been introduced into Africa. There are many Africans who cannot even accept the fact that plants such as cassava, corn, groundnuts and rice are foreign foods. On the basis of our past history, we already have the propensity to adapt to new food items.

In 1968 a book entitled "Food Composition Table for Use in Africa," was published jointly by the United States Department of Health, Education and Welfare (HEW) and the Food and Agriculture Organization of the United Nations (FAO). As its name implies, this work contains information on the protein, carbohydrate, mineral, vitamin and moisture content and the food energy value of many of the biological resources of Africa. The nutritive value of many plant and animal species has not been studied as yet. Nevertheless, this book is a good starting point from whence we could begin to take a hard look at the nutritive potential inherent in our biological resources.

Many of the food items discussed in the book are already being utilized in various sections of our societies. What is needed is the popularization of many of the foods not being utilized by introducing them into the commercial markets.

Summary

It is interesting to note that of the continents composed of developing countries, Africa is certainly the one in which most is known of its flora and fauna. The plant resources of Africa are certainly better known than those of South America. What is lacking is a rational asessment and utilization of the botanical resources of Africa. This is equally true of the level of our knowledge of the major faunal elements. Much work is needed to improve our knowledge of the biology of the small mammals and the lower plants.

Be that as it may, a number of our scientists (both pure and applied) and their administrative superiors are not even aware of the magnitude of and the potential inherent in our biological resources. It seems obvious that for African governments to obtain maximum utility from their biological resources, a concerted effort should be made to review the existing structures of scientific and technical organisations and to intensively review the native flora and fauna, so that their facility for solving problems and applying imaginative thinking to their research efforts can be realised to the fullest extent.

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A Polish Naturalist in Peru: The Life and Work of Felix Woytkowski

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Museums of natural history throughout the world are filled with specimens of animals and plants which bear labels telling where they originated, and when and by whom they were collected. Other label information may explain field conditions, abundance, and local importance where found. The names on labels of collecting localities and of collectors are necessary for adequate documentation and may be of much special importance if it is desired to revisit the locale for more material or to clarify some obscure aspects of the original collection. Apart from practical considerations, however, the student, whether expert or novice, using preserved specimens often develops a personal interest in a collector, whom at first he may know only as a name on labels. If those of us handling specimens do not know the collector's background, we often wonder what kind of person he was and whether his label data reflect accurate observations. Why did he devote time to such a pursuit in those perhaps long-past years? What were his life-style, his aspirations, and the nature of his family?

In future years, many scientists may wonder about Felix Woytkowski, whose name appears on the labels of thousands of insects and plants which he collected in Peru during 1929–64. This large body of material, located in numerous museums in the U. S. and elsewhere, is of so much importance, and Woytkowski's life was of such dedication to energetic collecting and the accumulation of accurate field data, that a short review of his career is timely because of an extensive recent biography (1, 2).

In 1929, at the age of 37, Felix Woytkowski arrived in Peru with his wife and 4-year old son; he left in broken health in 1965 to return to Poland, where he died in April 1966. For most of 35 years he actively studied the plant and insect life of Peru, chiefly as a collector who took pride in gathering specimens for leading professional botanists and entomologists who benefited from the carefully recorded information which accompanied the material. He travelled throughout most of Peru (his expedition itineraries list 16 Departments in which he collected) and noted the altitudes and zonal regions in which the various species occurred. Much of the country had never been examined with equal thoroughness by earlier collectors, so hundreds of species were new to science, and the information gathered about plants and insects as a whole was tremendous. Naturally, not all of the specimens added to museums or the data already published in basic descriptive papers have yet been synthesized in final form for biologists. In addition to collecting museum specimens, which he sometimes did on a part-time basis, he was associated for several years with San Marcos University in Lima, especially with the Botanical Garden there. Also, for 7 years he was employed by the Swiss firm, CIBA, in the search for plants of medicinal value. Thus, we see that Woytkowski's life was one of solid achievement on the frontier of science in the natural history studies of his adopted country.

Though for years Woytkowski contemplated writing a book about his work in Peru, was encouraged by many friends to do so, and took 3 chests of records (in Spanish and English) when he returned to Poland, he did not live to sort out the material. Later, his niece, Dr. M. Salomea Wielopolska, arranged and translated much of the material into Polish and assembled the manuscript of this book which, together with other information, is the basis for my brief biographical account. She then donated the Woytkowski records to the Polish Academy of Sciences in Warsaw (3).

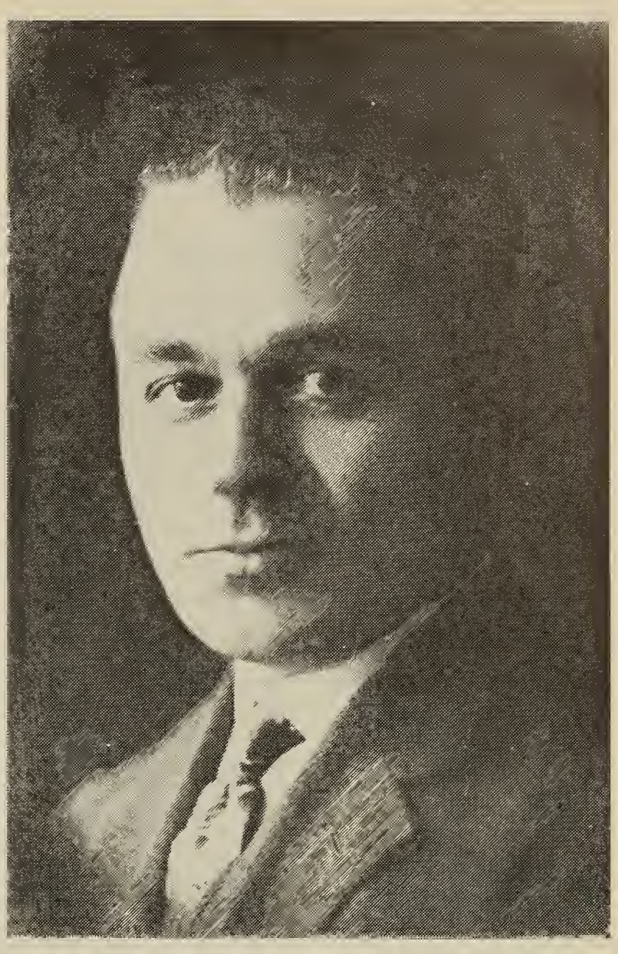

Fig. 1.—Felix Woytkowski at about 35.

Felix Woytkowski was born May 20, 1892 at Grzymalów in eastern Galicia, near the Zbrucz River which at that time was the boundary between Russia and Austria. In Poland of Pre-World War I, the Woytkowski family was one of comfortable financial position and social standing. Felix's father was a physician with a large practice who habitually treated those who were poor on a "gratis" basis, and Felix's grandfather had a large farm which included cultivated fruit trees from abroad, a botanical garden and heated greenhouses. In fact, the family had owned several estates and there was a tradition of pursuing agriculture and horticulture on a scientific basis. With this sort of background, Felix began when 12 years old, together with his brother Tadeuza, to collect insects and plants. An experienced botanist gave them guidance, and they made a large herbarium collection from local wooded hills which later was presented to the University of Lemberg (Lwow). The family could afford visits to other European countries, and the boys grew up familiar with libraries and museums, and they had an appreciation of cultural and scientific values.

Felix enjoyed music, painting, and literature, and the latter had a deep influence on him. This influence, as well as his command of the English language, is shown by sentiments later expressed in various letters and notes relative to his rich and varied experiences in Peru, for instance a paragraph quoted by Goodspeed (4): "The Andean heights, their utter wildness, their vast and silent alpine plateaus, their sheer descents into the Amazonian jungle, their mountain folk and the malignant spirits which for them haunt the high altitudes, create something which ever beckons anew. Within them there are glorious moments to live; there the air is freer and strangely inspiring; there one can learn some of the

Fig. 2.—Felix Woytkowski after returning to Poland.

elsewhere forgotten lore of ancient peoples; there plants and animals as well as air, sky and thoughts differ from anything we know here below. There we learn to conquer fear and suffering and satisfy our scientific curiosity in a vast kingdom of alluring adventure."

After completing secondary school in Lwow in 1911, Felix spent a year at Liege, Belgium at the "École des Hautes Études de Sciences Commerciales et Consulaires." Later, he studied at Oxford University, England, where he took economics and political sciences primarily, though he had a tutor to help perfect his English. With the outbreak of World War I, money from his parents was discontinued and he secured work in several grammar schools as a teacher of chemistry, Latin, Greek and other subjects. At Huddersfield he was a textile worker for a while and he became interested in the new ideas of Sir Sidney Webb concerning trade-unionism.

In 1918 a Polish army was organized in France by the Pole, General Joseph Heller, and Felix went there and enlisted as a volunteer, being assigned to the General's staff as an interpreter with the rank of Second Lieutenant. After the war he returned to Poland, where he first worked as the secretary of the Mayor of Warsaw. Later, in Graudenz, he was the foreign correspondent for the largest Polish foundry and enamel works. In 1923 he turned to agriculture and worked as an apprentice on 2 large estates. The war and the ensuing inflation created upset and impoverished conditions which, after he married and had the welfare of a wife and son to think of, led him to consider going abroad, first to Canada. However, he decided on Peru.

Felix and his family joined a group of Polish emigrants who arrived in Lima June 26, 1929, but he soon left the group in favor of a German colony at Villa Rica, Province of Tarma. Relating his experiences to C. P. Alexander in 1944, he wrote of soon finding it more difficult to make a living in Peru than in Europe. He also was attracted to the wooded surroundings and opportunities for natural history studies, then largely neglected in Peru. Woytkowski was a close friend of Pedro Paprzycki, another Pole who collected insects in Peru. After contacting specialists in the U. S., he found a ready market for specimens and for many years some of the same entomologists and botanists continued to receive material from him. Dr. Alexander, the veteran student of crane flies, H. B. Hungerford (Hemiptera), J. D. Hood (thrips), Leonora Gloyd (dragonflies), and F. M. Brown (butterflies) were among the entomologists who regularly received much useful material from him. T. H. Goodspeed (tobacco relatives and other plants), Charles Schweinfurth (orchids), and J. F. Macbride (Flora of Peru) were among the botanists for whom he worked especially. Through John D. Dwyer, a large collection of plants was acquired by the Missouri Botanical Garden, St. Louis, Missouri (5).

The itineraries of collecting trips presented in chart form on pp. 289–298 of the book are arranged by years and show altitude, the type of terrain, also the Province and Department of each locality where collecting occurred. Six folding maps held looseleaf inside the back cover show collecting localities, other place names and various routes traveled. The charts also indicate the chief periods of involvement at the Botanical Garden and with CIBA.

Throughout Woytkowski's book there are frequent references to Callanga, a Peruvian locality apparently first brought to his attention by Professor Hungerford who in 1929 had described an interesting new species of water-strider, *Velia helenae*, from there (6). A single female specimen of it, labelled "Callanga, Peru," without data or collector's name, had been found in the Riksmuseum, Stockholm, Sweden. Many insect specimens similarly labeled occur in several European and U. S. museums, and the abundance of unnamed species among them gave the impression of rich endemicity. Woytkowski has written that as early as 1935 he thought of going to Callanga to get more of the *Velia* as well as other hoped-for rarities, but he had difficulty in clarifying its exact location and in accumulating adequate funds to support the effort. Finally, after periods of great enthusiasm for doing so, as well as discouragement, he carried out explorations to Cuzco and nearby areas of southeastern Peru in 1951–53, including an early 1953 visit to Callanga, in southern Madre de Dios. He described going there, far down into a deep valley surrounded by steep hillsides, but he did not find *Velia helenae* and was much disappointed (7). There was some uncertainty whether the name Callanga represented a village or a river of the same name, and as a whole he felt that his Callanga trip was a failure (8).

It is sad to report that in spite of Woytkowski's skill as a collector he often was barely able by this occupation to support his family and his collecting trips, frequently away from home for many weeks. During 1946–55, when I purchased insect specimens from him, his letters often told of the urgent need for funds. On June 10, 1951 he wrote me of working a year in northwestern Peru for a petroleum company in order to finance a trip to southern Peru, "toiling daily within this vast corporation and living in the company's camp upon the barren desert of the tropical Pacific coast, so far north and so far from the Peruvian capital Lima." Later, near the end of his Peruvian work when afflicted by failing health, including *angina pectoris*, he was forced to sell his camera and equipment and was assisted by loyal friends in obtaining funds for the return to Poland. He had been divorced earlier, his only son George had died in 1952, and a grandson and two granddaughters apparently remained in Peru.

During Felix Woytkowski's life, warm appreciation for his work was expressed by various scientists (4, 9). Yet, in his final period of poor health and financial difficulty he may have wondered if his somewhat lonely life in Peru had been worthwhile. For many naturalists whose main work has been the collecting of specimens in places far from their original homes, life has brought relative obscurity, a precarious livelihood, dangers, sickness, and sometimes crushing disappointment when large collections were lost by shipwreck or deterioration from weather. Of course, it is different only in kind from the frustrations of innumerable human lives. In the case of Woytkowski, we have the published record of a very talented and dedicated naturalist, and he has left thousands of well preserved and carefully documented specimens which continue to enlarge the scientific studies of numerous other workers, improving the basic knowledge of South America. He will not be forgotten.

References and Notes

1. Peru-moja ziemia niebiecana (Peru-my unpromised land). 1974. by Felix Woytkowski. Translated into Polish and arranged by M. Salomea Wielopolska. 304 pp., 105 photos, 6 separate folded maps. Ossolineum (publisher), Wroclaw. Polish distributor: ARS Polona, Warsaw, Krakowskie Przedmiescie 7, Poland. Available in U. S. from International University Booksellers, 101 Fifth Ave., New York, N. Y. 10003. Paperback, $16.25. (The book may be translated into English.)

2. For generous assistance during the preparation of this biographical review I am indebted to numerous persons. George W. Byers and Peter D. Ashlock (University of Kansas) advised me about Woytkowski specimens obtained by

Dr. Hungerford. C. P. Alexander (Amherst, Massachusetts) opened up a large amount of information based on his long-term correspondence and put me in touch with Maria Salomea Wielopolska, who sent a copy of the book and enthusiastically answered numerous detailed questions. The Polish Academy of Sciences kindly furnished photographs. Several local friends and colleagues have been helpful, particularly Eugene Jarosewich (Mineral Sciences, U. S. National Museum of Natural History) and my neighbors Frank and Gene Gonet, who translated paragraphs of Polish for me. John J. Wurdack (Botany, U.S.N.M.N.H.) has been especially helpful with references to Woytkowski's botanical work. Finally, Gerardo Lamas of Lima, Peru, a visiting entomologist, gave me a clearer insight into Woytkowski's collecting localities.

3. Dr. Wielopolska, now retired and occupied with writing tasks, was for 25 years the Chief Librarian at the Technical University in Szczecin. She has always been interested in natural history and early began the serious study of forestry, which, however, was interrupted by World War II, after which she pursued a career in liberal arts and library science.

4. Goodspeed, T. H. Plant Hunters in the Andes (2nd Ed.) 378 pp., Univ. of California Press (1961).

5. Dwyer, J. D. A preliminary report on Woytkowski's last Peruvian collection. *Phytologia*, vol. 15: 458–461 (1968); La coleccion de plantas peruanas de Felix Woytkowski en el Missouri Botanical Garden (1958–1962). *Raymondiana*, vol. 4: 5–71 (1971). (The second paper is nearly identical to the first one except that a large list of plants, some 2,000 species in number, is included).

6. Hungerford, H. B. A new *Velia* from Peru (Homoptera, Veliidae). *Entomol. Tidskrift* (Stockholm), vol. 50: 146–147 (1929).

7. Additional Peruvian specimens of *helenae* have since been reported from the Department of Junin. Polhemus, J. T. A new *Velia* from Peru, and the description of the male of *Velia helenae* Hungerford. *Proc. Entomol. Soc. Washington*, vol. 71: 55–59 (1969).

8. One of the folding maps accompanying the book was prepared by Prof. Hungerford to show the supposed location of Callanga, and it probably was based on data sent to him by Woytkowski. The map was sent to Woytkowski with a letter dated March 31, 1953. after the expedition was completed, but neither of them was certain of the significance of "Callanga." From Gerardo Lamas of Lima I have now learned that Callanga was a hacienda which was visited much earlier by one or more individual collectors, chiefly Gustav Garlepp (1862–1907), a German who made 4 South American trips between 1883 and 1907, when he died in Paraguay by a "treacherous murder." Garlepp, sometimes aided by his brother Otto, collected actively and specimens were distributed widely, mainly through the firm of Staudinger and Bang-Haas of Dresden. He probably was in Callanga about 1890. Accounts of the Garlepps were written by Niethammer (Bonner Zoologische Beitrage, vol. 4: 195–303, 1953) and Papavero (Essays on the History of Neotropical Dipterology, vol. 2: 293–295, 1973). Callanga was destroyed by Indians in this century, perhaps about 1940, according to Dr. Lamas' information, and at the time of Woytkowski's visit remnants of the single hacienda (farm) were all that remained. It was located at about 12.59 S. Lat., 71.13 W. Long., at an altitude of about 1500 m. Some collections from "Callanga" may have been taken at different elevations in the neighborhood of the hacienda.

9. Soukup, J. Felix Woytkowski, veinticinco anos dedicados a biología. *Biota*, vol. 1: 30–33, 1 fig. (1954); Felix Woytkowski (1892–1966). *Biota*, vol. 6: 150–153, 1 fig. (1966).

A New Species of Platycystites *(Echinodermata: Paracrinoidea) From the Middle Ordovician of Oklahoma*

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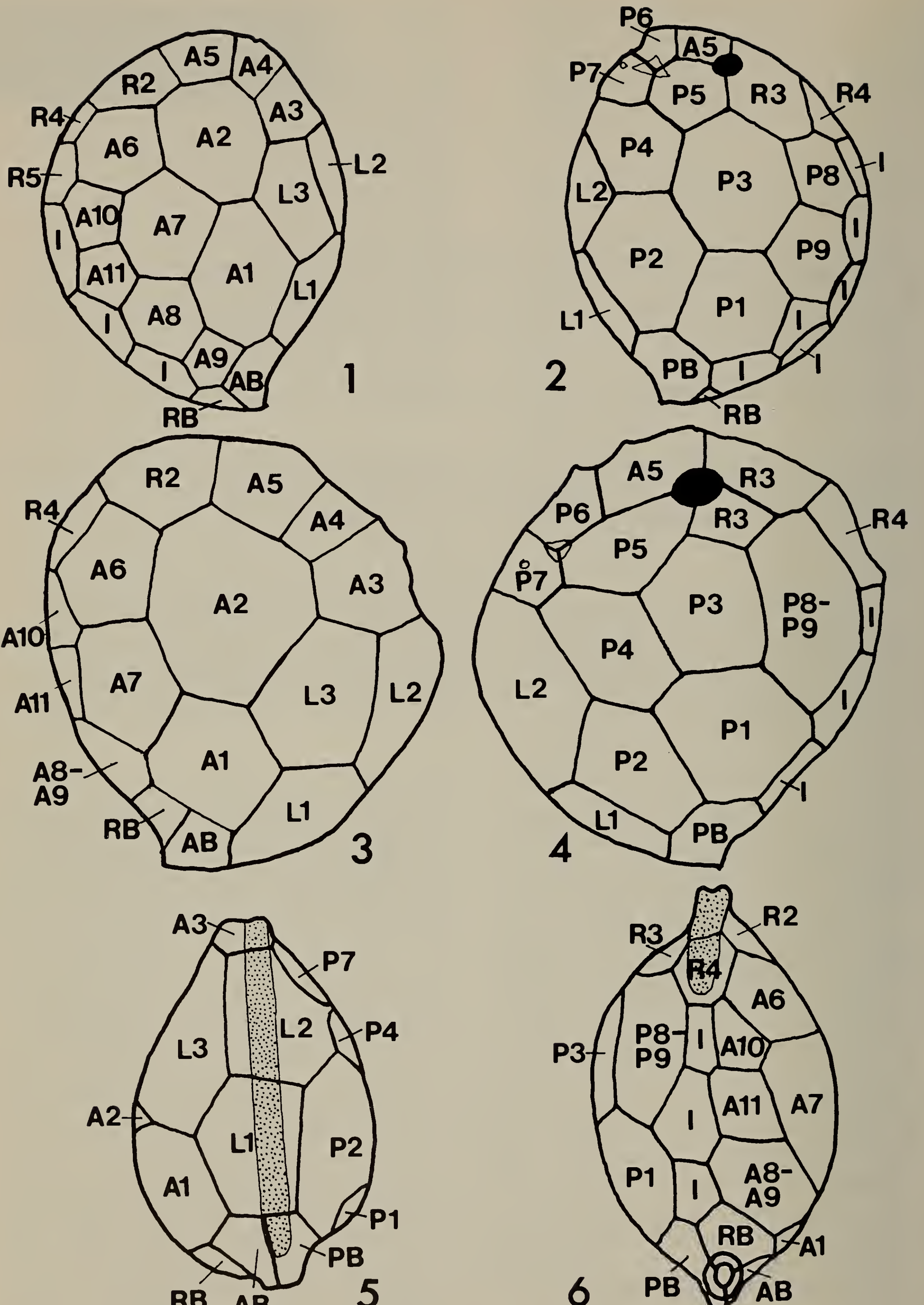
ABSTRACT

The paracrinoid *Platycystites infundus*, new species, from the Bromide Formation (Middle Ordovician) of Oklahoma provides additional evidence that at least some paracrinoids lay upon the substrate or partially embedded on it. The inferred mode of life, based on stem attachment and thecal morphology, of the 3 species now ascribed to *Platycystites* suggests that only 1 (*P. faberi* Miller) was held erect above the sea bottom by its column.

The rare paracrinoid genus *Platycystites* (Order Platycystitida Parsley and Mintz, 1975) is presently known only from southwest Virgina, northeast Tennessee, and southern Oklahoma. Like most other paracrinoids it is restricted to rocks of Middle Ordovician (Blackriverian) age. *P. faberi*, type species of the genus, was inadequately described and illustrated by Miller (1889), who also presented incorrect occurrence data for the species. No further species were added to the genus until Bassler (1943) proposed several new species (*P. bromidensis*, *P. cristatus*, *P. fimbriatus*, *P. levatus*), all from the Bromide Formation (?Chazyan-Blackriverian) of Oklahoma. Another Bromide species (*P. bassleri*) was added by Sinclair (1945).

Though the distinctness of the genera now grouped in the Paracrinoidea had long been recognized, the group was not raised to class status until 1945 (Regnell, 1945). By far the most comprehensive treatment of the paracrinoids is that of Parsley and Mintz (1975). In their paper they redescribed and reillustrated *P. faberi* and reduced all of the Bromide species into synonymy with *P. cristatus* Bassler. Apparently all of the Bromide specimens studied by Bassler and Parsley and Mintz came from the lower echinoderm zone (informally designated the "*Platycystites* zone") of the Mountain Lake Member, in which *Platycystites* is prolific. The total thickness of the beds through which *P. cristatus* ranges is about 65 ft, but all are from the lower part of the Mountain Lake (Parsley and Mintz, 1975: 74). The single specimen described herein as *Platycystites infundus*, n. sp., was collected by McGinnis from an exposure of the upper echinoderm zone (of Fay and Graffham, 1969: 37–42) which occurs at the top of the Mountain Lake, considerably above the "*Platycystites* zone." The echinoderm fauna of this unit (informally termed the



Figs. 1–6.—Plate diagrams of *Platycystites*. 1, 2, Anterior and posterior views of *P. cristatus* (modified from Parsley and Mintz, 1975, text-fig. 3); 3–6, anterior, posterior, left, and right views of holotype of *P. infundus*. A-anterior plates; AB anterior basal; L, left plates; P, posterior plates; PB, posterior basal; R, right plates; RB, right basal. Periproct black; positions of gonopore and hydropore indicated by light lines.

"*Oklahomacystis* zone") differs considerably from that lower in the Mountain Lake. The paracrinoid genera *Oklahomacystis* and *Sinclairocystis* have not been found outside the zone and appear to be endemic to this unit. A single specimen of *Platycystites* has been collected from the *Oklahomacystis* zone at a locality near Sulphur, Oklahoma; the specimen lacks the arms and stem but it is preserved as well as are most paracrinoids. This part of the Bromide is not well exposed and the source exposure is no longer collectible: J. Sprinkle (pers. comm., 1976) reports that around 45 specimens, possibly referable to *P. faberi*, have been collected from this zone in the western Arburckle Mts. (Oklahoma). None of these apparently are referable to either *P. cristatus* or *P. infundus*, n. sp.; hence it is unlikely that any additional specimens of *P. infundus* will be discovered in the near future. Despite its imperfections, the specimen preserves most important morphological features and is clearly a distinct species.

The addition of a third species to *Platycystites* necessitates some reevaluation of the functional morphology of the genus. In particular the thecal shape and position of the stem facet of *P. infundus*, n. sp., support the contention of Durham (in Parsley and Mintz, p. 69, figure 6) that at least some species of this genus were recumbent upon or partly buried in the substrate with the stem acting as an anchor or as a tether rather than serving to elevate the theca above the sea bottom as Parsley and Mintz (*op. cit.*) envision it. Nevertheless, we have used Parsley and Mintz's descriptive terminology and orientations which are partly predicated on the assumption that their reconstruction of the living position of *Platycystites* is correct. The system they employ facilitates homologous comparisons between the genus and other paracrinoids, particularly within the Platycystitida. It can be applied with little modification to *P. infundus*. Its use does not, however, imply acceptance of their interpretation of the genus' mode of life.

Higher classification of many of the poorly known fossil echinoderm classes is currently in a state of flux. As regards the Paracrinoidea we have followed the taxonomy of Parsley and Mintz through the ordinal and class levels but refrain from assignment of the class to a subphylum. Parsley and Mintz (1975: 5–7, 25–26) erected the subphylum Paracrinozoa, with the single class Paracrinoidea, for this distinctive group of echinoderms because, according to these authors, the paracrinoids cannot be placed in either the Crinozoa (Matsumoto, 1929) or Blastozoa (Sprinkle, 1973). Briefly the justification for this action is that the Paracrinoidea "have characteristics that fit into both subphyla mentioned above and they also have traits which are peculiar to their own subphylum, e.g. internally opening transutural slits, left lateral offset peristome relative to the column, along with a pronounced plate increase in the right lateral margin and bilateral symmetry defined by the G plane" (*op. cit.*, p. 26). While these characters collectively discriminate the Paracrinoidea from other echinoderm classes, none of them individually are unique to it. Some features of the paracrinoid thecal plate pore system are strikingly reminiscent of those of eocrinoids; more detailed analysis of it is required to establish its uniqueness, particularly since one order of Paracrinoidea (Platycystitida) totally lacks a pore system. Bilateral symmetry defined by the G plane is also developed in some Rhombifera (e.g. *Pseudocrinites*; see Paul, 1967 and Kesling, 1968 for discussion). Lateral offset of the peristome also occurs in other groups; examples include *Columbocystis* (uncertain affinities) and the diploporid cystoid *Allocystites* (Parsley, 1975: 356–357).

The validity of the subphylum Blastozoa Sprinkle has recently been questioned by Breimer and Ubaghs (1974a), and Breimer and Macurda (1972) and Macurda (1973) have presented morphologic data indicating the presence of tube feet in the Blastoidea, *contra* Sprinkle. Without attempting to evaluate the merits of the various points raised by these authors, it is fair to say that a consensus has not yet emerged. The basic data required to establish which characters are of importance at the highest levels of echinoderm taxonomy are still largely lacking. While quite recently major essentially solid taxonomic contributions such as those of Parsley and Mintz (1975) and Sprinkle (1973) have greatly clarified the status of a number of puzzling fossil echinoderms, it seems reasonable to expect that the current information explosion in the study of primitive echinoderms will continue for some time. Consequently we feel that large scale rearrangements of the echinoderm clases and, particularly, a proliferation of subphyla are premature. We follow Parsley and Mintz (1975) and Breimer and Ubaghs (1974b) in removing the Paracrinoidea from the Crinozoa, but like the latter authors do not place it in a subphylum. We admit the strong possibility that the Paracrinozoa of Parsley and Mintz may eventually prove fully acceptable to most workers.

Systematic Description

Class PARACRINOIDEA Regnell, 1945

Order PLATYCYSTITIDA Parsley and Mintz, 1975

Diagnosis.—"Paracrinoids without sutural pores; arms epithecal, typically branched; thecal plates generally smooth with pustulose prosopon" (Parsley and Mintz, 1975: 57).

Family PLATYCYSTITIDAE Parsley and Mintz, 1975

Diagnosis.—Theca ovoid to amygdaloid in shape with approximately 27 plates identifiable in juveniles, plus a variable number of intercalates along the right side (some are generally present). Arms 2, transverse, primarily epithecal (adopted from Parsley and Mintz, 1975: 58).

Genus PLATYCYSTITES Miller, 1889

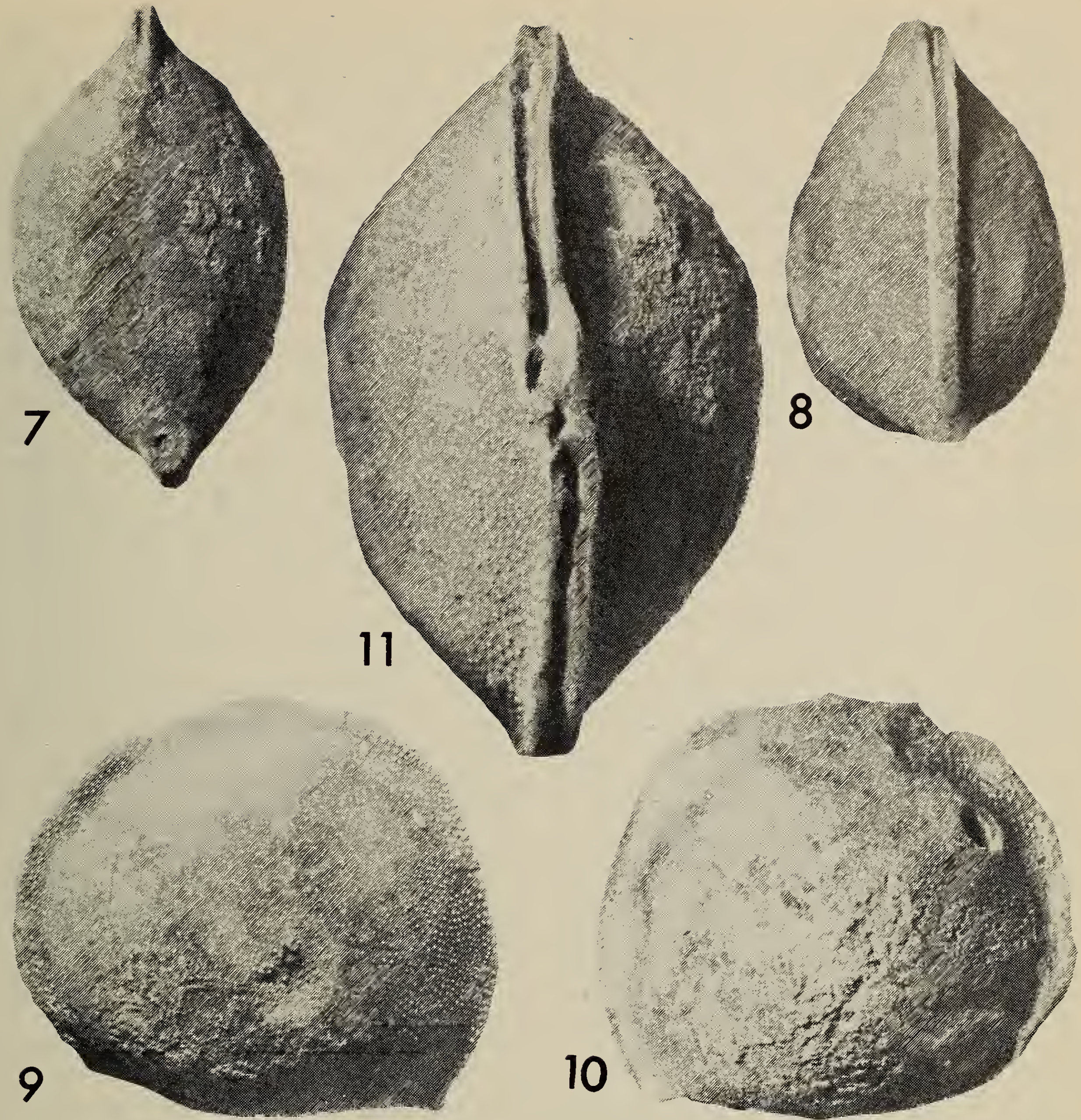
1889. *Platycystites* Miller, North American Geology and Paleontology, p. 272.
1900. *Platycystis* Miller, Bather, in Lankester (ed.) Treatise on Zoology. III, Echinoderma, p. 51.
1911. *Platycystis* Miller, Kirk, U. S. Nat. Mus. Proc. 41: 19.
1913. *Platycystites* Miller, Bather, Roy. Soc. Edinburgh, Trans. 49 (pt. 2) (6): 371.
1913. *Anomalocystites* Hall, Springer, in Zittel-Eastman, Textbook of Paleontology, vol. 1, p. 150.
1943. *Platycystites* Miller, Bassler, Amer. Jour. Sci. 241: 669–697.
1945. *Platycystites* Miller, Regnéll, Lunds Geol. Min. Inst., Medd., No. 188, p. 39.
1945. *Platycystites* Miller, Sinclair, Amer. Midland Nat. 34(3): 707.
1968. *Platycystites* Miller, Kesling, Treatise on Invertebrate Paleontology Part 5. (Echinodermata 3) 1: 288.
1975. *Platycystites* Miller, Parsley and Mintz, Bull. Amer. Pal. 68(288): 59.

Diagnosis.—Theca amygdaloidal, compressed to broadly oval and inflated in cross section, with 27 to 29 identifiable plates; some species with additional intercalates along right lateral margin; maximum number of plates about 47. Peristome usually only slightly offset to left, periproct on posterior face near upper margin. Arms 2, epithecal, extending varying distances along the lateral margins (modified from Parsley and Mintz, p. 59).

Type species.—Platycystites faberi Miller, 1889.

Range.—Middle Ordovician (Blackriverian); Bromide Formation, Oklahoma; Ottosee-Benbolt, Virginia and Tennessee.

Remarks.—Our generic diagnosis differs only slightly from that of Parsley and Mintz; the main difference is that we do not recognize the presence of intercalates in the type species. Our interpretation of thecal plating in *P. faberi* will be presented in a forthcoming paper. For convenience the theca is oriented in the plate diagrams with the periproct uppermost and the stem roughly opposite the periproct defining a vertical longitudinal axis. This orientation is not identical, in the opinion of the authors, to that of the whole animal in life position except possibly in *P. faberi*. Thecal plate nomenclature and face terminologies



Figs. 7–11.—Holotype of *Platycystites infundus*, n. sp.; 7–10, views of right, left, posterior, anterior sides, all magnified ×2.7 (9 and 10 are side views in presumed life orientation); 11, top view, centered on peristome in presumed life orientation, ×4.0.

are those of Parsley and Mintz as summarized in their text-figure 3 (*ibid*, p. 60; compare the explanation of our figs. 1–6) except in minor details. The terms right and left are defined relative to the posterior face when the theca is viewed in anterior-posterior profile as in fig. 2 and 4.

Platycystites infundus, n. sp.

Figures 3–11

Diagnosis.—Theca with about 33 plates, few intercalates, not strongly inflated. Arm calluses prominently developed, left arm nearly reaching column. Theca strongly asymmetric, right side flattened. Stem facet directed toward right.

Material.—One specimen, holotype SUI 39513, from the "*Oklahomacystis* zone," top of the Bromide Formation, Mountain Lake Member, 1.8 mi. Sulphur, Oklahoma.

Description.—Theca unevenly rounded in anterior-posterior profile; largest dimensions subequal, length of holotype 22.0 mm; maximum width of holotype 21.7 mm. Total number of thecal plates about 33; few of these are intercalates (3 on holotype). Theca flattened along right side, evenly oval in outline when viewed along a plane normal to axis through gonopore and hydropore and center of right side (fig. 11). Stem facet elliptical, not crenulate, narrow, width 2.1 × 2.0 mm, oriented parallel to proximal distal axis. Lumen small, round, diameter 0.7 mm.

Basals 3, unequal; PB and AB large, equal in area, developed on posterior and anterior faces and left margin of theca. RB short, much smaller in area than PB or AB, making up less than one-third of column attachment facet. Left plates 3: L1 and L2 crossing thecal margin; L1 situated immediately above PB and AB, hexagonal, crossed transversely by left arm, developed more on anterior face; L2 above L1, 6-sided, arm callus traversing the plate along its long axis, most of plate area on posterior side. L3 to left of other left plates, pentagonal, wholly on anterior face.

The 10 anterior plates plus the left plates make up most of the anterior thecal face (figs. 3 and 9). Subcentral on the anterior face is the large A2, bordered by 8 plates. Immediately beneath A2 is A1, a heptagonal plate that frequently is the largest anterior thecal element in *P. cristatus* (Parsley and Mintz, p. 62) but in this species is considerably smaller than A2. A6 and A7, subequal in area, border A2 on the left; A6 is nearly equally 5-sided; A7 is irregularly hexagonal. Most of the left anterior border is made up of 3 small plates (A10, A11, A8–9) which do not extend more than half way around the left side of the theca. A10 and A11 are small and unequally pentagonal; the single plate presumed to represent A8 and A9 in *P. cristatus* (fig. 1) is heptagonal and adjoins A11 and RB laterally along the lower left anterior margin. Adoral to A10 is R4, a small hexagonal element visible on both sides of the theca and bisected by the right arm seat which terminates on this plate (figs. 6 and 7). No plate corresponding to R5 of *P. cristatus* is present on the holotype of *P. infundus*. R2, plus anteriors A3, A4, and A5 fill out the upper margin of the anterior face. These plates are quite small in *P. cristatus*; they are larger in area in this species, presumably because of the more extensively protruded arm tracks. A2 and A3 are pentagonal; their upper edges terminate on the anterior face, as does that of the small 4-sided A4. A5 is equally developed on both faces; this plate forms the northwest quadrant of the periproct border on the posterior face.

The periproct, located near the upper margin on the posterior face, is surrounded by 4 plates, each of which subtends an equal area of its border. The right half of the periproct border is formed by R3, which is bipartite; A5 and P5 also contribute to the periproct border. The periproct opening itself is raised slightly and circular (diameter 2.2 mm). A presumed hydropore is located at the junction of P5, P6, and P7; the opening itself cannot be seen, but it is likely situated on the small raised triangular platform visible where these 3 plates meet (figs. 4, 10). A small round pore (gonopore), central on a raised tubercle, occurs on P7. All plates along the upper margin of the posterior face are elongated parallel to the thecal margin. Between R3 and PB the right posterior margin is made up of R4 and 3 small intercalates. Distal to P7 the left posterior margin is defined by L2, L1, and PB. L2 passes over onto the anterior face but is mostly posterior in position. The central area of the face is occupied by relatively few, large plates, i.e., P1–P5 and P8–9. P1, the largest posterior plate, and P4 are hexagonal; the pentagonal P2 and P3 are subordinate in size to P1 and P8–9 in this species (compare *P. cristatus*, fig. 2). The elongate irregular shape of P8–9 is unusual; this plate may be abnormal in this specimen and more usually 2 discrete elements may be present as in *P. cristatus*.

Calluses for the epithecal arms are narrow (average width 1.1 mm) but prominently extended out from the theca throughout their length (figs. 9–11). The left arm extends around the theca to about the midheight of PB before becoming exothecal or terminating. The right arm callus does not extend below R4. None of the arm plates themselves are retained. The proximal part of the left arm callus, and nearly all of the right arm, is invaginated into the theca, forming a trough. Proximal to the oral opening the troughs appear to penetrate the bottom of the callus, which is thus open to the interior. The thecal plates, except in the areas making up the arm calluses, are covered with a fine pustulose prosopon. The column is unknown.

Derivation of name.—The specific epithet refers to the presumed life habit of the species (*infundus*, laid out upon, spread on).

Remarks.—*Platycystites infundus*, n. sp., differs from *P. cristatus* in a number of ways as noted above; but given the limited material on which *P. infundus* is based and the small number of described *Platycystites* species, the value of many of the noted features of the holotype as taxobases on the specific level is uncertain. Only *P. cristatus* is known from a reasonably large number of specimens and has been described at length. A definitive plate diagram of *P. faberi*, together with detailed descriptions of thecal plate identities and locations based on a large series of specimens, would facilitate platycystitid taxonomy but such a series in unlikely to be available in the near future. In their absence the following discussion is based primarily on *P. cristatus*.

Some degree of variation in thecal plate number has been noted by Parsley and Mintz (*ibid.*, p. 73) in *P. cristatus*; most variable is the number of intercalates, which can range between 2 and 17 in this species. The other thecal plates are less variable; their number is largely independent of thecal size (height), they are in more or less fixed position, and, though their outline may vary, they are readily identifiable from specimen to specimen (*ibid.*, p. 60). It is hence possible that many of the deviations from *P. cristatus* noted in the description of *P. infundus* (e.g. bipartite R3, combined A8–9 and P8–9, R5 missing or combined with R4) may be significant at the specific level. On the other hand, some of these variations could also occur on an abnormal specimen, but when combined with other noted differences they may be utilized with more confidence. Possibly some of these features are related to life habit. Paired small plates (*i.e.*, A10 and A11, A8 and A9, P8 and P9 in *P. cristatus*) may have originated through bisection of what was originally a single element. Replacement of a single plate (normal condition for the population) by 2 elements in some individuals is known in some Rhombifera: Paul (1966, 1968) figures 2 examples of such arrangements in *Glansicystis baccata* (Forbes). A specimen of *P. faberi* in the University of Iowa collection (SUI 39514) also has combined A10–11 and A8–9 into single plates. If *P. faberi* represents the more primitive platycystitid form, then the apparent increase in number of major thecal elements in *P. cristatus* and *P. infundus* may be both a phenotypic and genotypic response to a changed life habit (i.e. recumbent versus erect theca). In the 3 known species of *Platycystites* there is a direct correlation between the number of thecal plates and the degree of thecal inflation; the highly inflated *P. cristatus* has the largest number of regular and intercalate plates while the compressed *P. faberi* has the least of both. As might be expected *P. infundus* has intermediate numbers of both plate types.

Many of the differences in plate proportions between the 2 species may similarly be interpreted as due to individual variation rather than as valid specific features. Some undoubtedly result from unlike thecal outlines. Gross shape varies somewhat from individual to individual in *P. cristatus* but is a useful taxobasis if used cautiously. The holotype of *P. infundus* falls outside the normal range of variation of *P. cristatus* as regards thecal shape. Probably the greater area of the upper marginal plates in *P. infundus*, which is related to the degree of extension of the arm tracks, is also not simply a feature of this particular specimen. The flattening of the right side of the holotype of *P. infundus* is not due to distortion but appears to be an original feature. We believe that it served to stabilize a theca which was recumbent on the sea bottom; in fact the fossil specimen is stable at rest in the position illustrated in figs. 9 and 10. The orientation of the stem facet, which is diametrically opposite to that of *P. cristatus*, (compare figs. 2 and 4) is consistent with this interpretation. Other points of difference between the 2 are likely of minor importance or cannot be evaluated on the basis of present material. *P. infundus* has a coarser pustulate prosopon on the plate surfaces than typical *P. cristatus*; but similar specimens of the latter have been observed. The small number of intercalates in *P. infundus* could be an artifact of limited material; we believe, however, that this feature is specific to the species. With its flat right side and less expanded theca (*P. cristatus* is greatly inflated in this area) there is less need for extra thecal elements.

Altogether we feel that there are enough points of difference of significance to justify the separation of the "*Oklahomacystis* zone" specimen from *P. cristatus* at the specific level in spite of the lack of a large group of similar specimens. In terms of gross thecal morphology and plate arrangement, *P. infundus* is closer to *P. cristatus* than to *P. faberi* and has most likely evolved from the former species.

Functional Morphology

Two current interpretations of the life habit of Paracrinoidea (and *Platycystites*) have the theca strongly canted to the right, with the peristome uppermost and the tips of the epithecal arms defining a plane parallel to the substrate surface. Parsley and Mintz (*ibid*, p. 22) believed that the theca was raised off the sea bottom by the stem, which would have been relatively rigid. Conversely, Durham would place the near horizontal arm termination plane at the sediment-water interface. In this model the theca would be partly buried with the possibly distally flexible stem serving as a subsurface anchor (*ibid*, p. 22, test-fig. 6). A third possibility is that the paracrinoid stems were "runners" somewhat in the manner of calceocrinids with the theca lying on the substrate surface, peristome uppermost, tethered by its stem. Parsley and Mintz's interpretation is most plausible for the majority of paracrinoids which are not strongly asymmetric. For genera like *Platycystites* we believe that Durham's hypothesis is more plausible. The addition of *P. infundus* to the genus provides some additional information on *Platycystites* mode of life.

In their discussion of *Platycystites* Parsley and Mintz (*ibid.*, p. 69) considered *P. faberi* and *P. cristatus* collectively, as though both were functionally and morphologically identical: actually they have quite different morphological features. The restoration of *P. cristatus* which they illustrate (*ibid.*, text-fig. 6), reflecting the opinion of J. Wyatt Durham on its living position, is probably most nearly correct for this species and for *P. infundus*, but it very likely does not apply to *P. faberi*. The situation in *Platycystites* might be more complex than visualized by previous authors.

P. faberi has a thin compressed pear-shaped theca with the peristome and columnar attachment area forming a vertical axis. Both the right and left epithecal arms extend from the mouth to, or nearly to, the column. The animal was almost perfectly bilaterally symmetrical and was no doubt held above the substrate on a column. No complete specimens are known; hence it is not possible to determine with certainty whether or not the theca was canted by a flexure of the proximal column as Parsley and Mintz (*ibid.*, text-fig. 1) illustrate for *Amygdalocystites florealis* and infer for most paracrinoids. We believe that the horizontal plane defined by the arm terminations reflects the living orientation in all paracrinoids; we suspect that the theca of *P. faberi* was not canted and that the supporting column continued from its junction with the theca, unbent proximally and aligned with the longitudinal axis of the theca. Like the theca, the column of *P. faberi* was probably usually upright and vertical. In this position the periproct would be offset slightly to the right of the peristome while the peristome, gonopore, and hydropore would be uppermost. The periproct would thus be at a slightly lower level than the peristome and associated thecal openings, thus tending to remove anal wastes from its vicinity. It is difficult to conceive of any manner in which fouling of the subvective appendages could be avoided if the theca of *P. faberi* were in contact with or partly buried in the substrate.

P. cristatus and *P. infundus* have modified the theca to a strongly asymmetric shape. *P. cristatus* is greatly inflated on the right side proximal to the column; this area of the theca is broadly rounded. The equivalent thecal surface in *P. infundus* is flattened and the theca is not as rounded in profile. As noted by Durham (in Parsley and Mintz) the right arm of *P. cristatus* is always short and does not extend into the expanded area proximal to the column which is presumed to contact the sea floor; the right arm track of *P. infundus* is similarly limited. Conversely, in both species the left arm, which would be above the sea floor in Durham's and our reconstruction, extends nearly the full length of the left side of the theca; in some specimens it may even extend onto the column. These features are shared with *Amygdalocystites florealis*, which also may have had the theca in contact with the substrate. Possibly the same 2 modes of living postulated for *Platycystites* had their equivalents in *Amygdalocystites*: most species, like *A. florealis*, have a bend in the column proximal to the theca, but the poorly known *A. radiatus* appears to lack it (Parsley and Mintz, p. 51). An undescribed species of *Amygdalocystites* from the Dunleith (Middle Ordovician) of northern Iowa, currently being studied by T. W. Broadhead (University of Iowa), has a proximally unflexed column and 2 long equal epithecal arms. Its thecal shape is similar to that of *P. faberi* and its life habitus was probably comparable. If the erect life orientation suggested by Parsley and Mintz were correct and universal within these 2 genera we see no reason why both arms in all species should not be equal in length. It is probable, in our opinion, that major differences in thecal symmetry within a genus reflect differing life habits, especially if modifications of symmetry correlate with other morphological changes. A thecal morphology and arm arrangement comparable to that of *P. faberi* is present in other echinoderm classes; at least 1 similarly-shaped rhombiferan (*Pseudocrinites*) has 2 recumbent ambulacra extending down the theca onto the column. The Parsley and Mintz model would, we feel, require the column to be strong and relatively rigid throughout its length; however complete columns are exceedingly rare. Not uncommonly specimens of *A. florealis* and *P. cristatus* do retain the proximal flexed, presumably ankylosed, part of the column. This is more consonant, in our opinion, with Durham's model or with a bottom-runner life habit.

Pronounced asymmetry of the theca accompanied by a small column which may be bent abruptly backward next to the theca is not uncommon in other paracrinoids. According to Hudson (1905) the stem of *Canadocystis emmonsi* "appears to have been short and used perhaps for an anchor, but not for complete support." Hudson further suggests that the ancestors of these paracrinoids "were once supported by the stem alone and had their arms in a normal position, but that descendants with weak stems often found themselves let down to the ocean floor and had to make shift to live under adverse conditions. Increased growth of the posterior side or decreased growth of the anterior plates would have brought the arms again uppermost to a form like that shown here." Allowing for differences in terminology and emphasis the theme of Hudson's observations is not far removed from our conclusions herein.

Durham (in Parsley and Mintz) believed that there was a discernable difference in prosopon below the supposed termination plane in some specimens of *P. cristatus*. We, like Parsley and Mintz, have been unable to detect this difference on the specimens we have examined; but this does not in our opinion weaken Durham's argument in any way. Other counterarguments advanced by Parsley and Mintz (p. 22) also do not seem compelling. Preserved columns of *Amygdalocystites* and *Platycystites* with the cited morphological features (proximal flexure and ankylosis) are quite short, and it is not surprising that they do not show a distal taper. *Comarocystites* undoubtedly has a holdfast and relatively long straight column and almost certainly was held erect; but this genus does not show pronounced thecal asymmetry or a differential expansion of one side of the theca. Holdfasts and lengthy stems have not been reported for *Platycystites* or *Amygdalocystites*. We do not believe that either Durham's model or that of Parsley and Mintz apply to all paracrinoids. If the Paracrinoidea is a valid taxon of class rank it would be surprising if one mode of living was adopted by all members; considering the morphologic diversity of the known paracrinoids this possibility becomes vanishingly small. Investigation of each paracrinoid genus individually might yield more accurate information about the class' paleoecology than does the attempt to apply a single over-extended, albeit useful, model to the class *in toto*.

Information about the length of the entire column and the nature of the adult attachment device, if any, in *Platycystites* is lacking. It is worth noting, however, that a possible future find of a long column and holdfast in a species like *P. cristatus* would not necessarily invalidate Durham's hypothesis. The reconstruction in Parsley and Mintz shows an abrupt stem termination, but it is possible that the species was attached when young and lost the stem terminus as it approached maturity. Alternatively it is also possible that the theca merely lay on the surface of, rather than partly embedded in, the substrate. If such were the case the largely flexible stem, doubled back under the theca, would have served as a tether of a theca which could adjust its living position in a manner analogous to that suggested by Kesling and Sigler (1969) for the Calceocrinidae: in this model the length of the stem is irrelevant, and in fact calceocrinid stems shorter than the crown or many times its length have both been reported (Brower, 1966). Like Parsley and Mintz we postulate that many paracrinoids were rheophilic; our model, or a modification of Durham's, would give the animal a greater ability to adjust to a changing current regimen than would that of Parsley and Mintz. In either case the streamlined bilaterally symmetrical theca and concomitantly reduced subvective system are supportive of a rheophilic habit. Definitive evidence allowing the elimination of one or the other major alternative interpretations of living position has not yet appeared.

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Evolutionary and Paleoecologic Significance of Abnormal Platycystites cristatus *Bassler (Echinodermata: Paracrinoidea)*

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ABSTRACT

Two specimens of the common Bromide Formation (Middle Ordovician; Oklahoma) paracrinoid *Platycystites cristatus* Bassler have 3 epithecal arms instead of the normal 2. Analysis of the location and mode of branching of these specimens supports the suggestion of Parsley & Mintz (1975) that the paracrinoid ancestor had 2 epithecal arms. One specimen also has a portion of a column embedded in its right side; the column location and thecal shape indicate that the life position of the animal was with the theca recumbent on the sea floor.

Three-Armed *Platycystites cristatus*

The rare fossil echinoderm class Paracrinoidea (Regnéll, 1945) exhibits considerable morphologic diversity despite its restricted range and distribution (Middle-Upper Ordovician, almost exclusively North American) and the small number of member taxa (9 genera) as presently known. Only 2 species, *Platycystites cristatus* Bassler and *Oklahomacystis tribrachiatus* (Bassler), are represented by large numbers of individuals. The class recently has been monographed comprehensively by Parsley & Mintz (1975). While their work was primarily a taxonomic treatment of North American paracrinoids they also briefly present some data bearing on the phylogeny of the group (Parsley and Mintz, 1975: 11–15). Their tentative comments are based on the assumption that the so-called cystidean transverse arm pair is more primitive than the triradiate condition favored by some authors (Parsley and Mintz, 1975: 12, footnote). More particularly they infer that the primitive subvective condition in paracrinoids was also a primary transverse pair of epithecal arms, and that the exothecal, more-than-2-armed condition present in some genera of both paracrinoid orders is more advanced. Those genera which have more than 2 arms (e.g. *Oklahomacystis*) are believed to have acquired the extra subvective elements by branching of 1 or both members of the primary pair (Parsley and Mintz, 1975: 11).

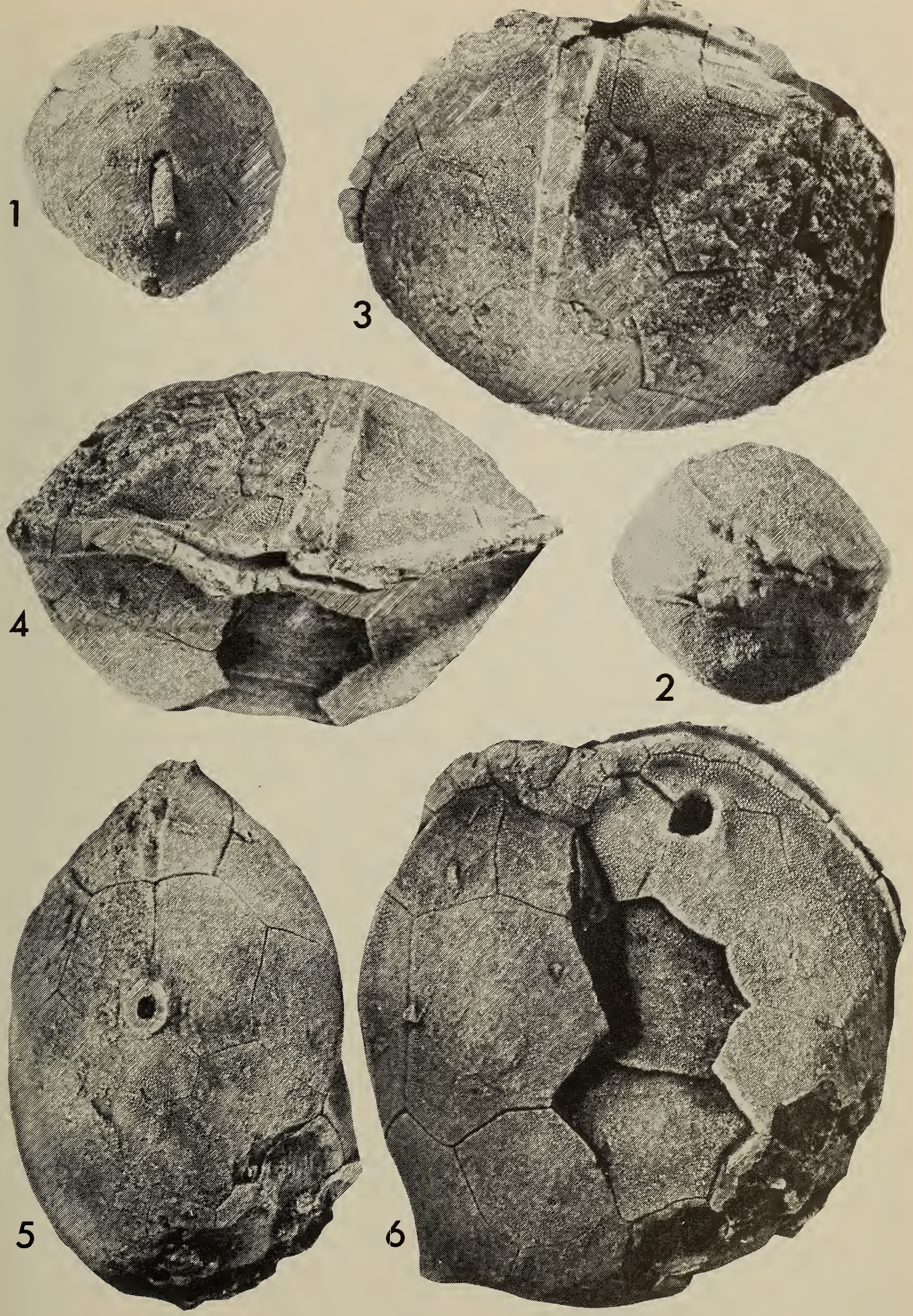
The acquisition of an extra arm probably is a solution to the problem of increasing the proportion of subvective area relative to the total thecal volume: this would increase food gathering capacity and hence make the species a more effective competitor with other echinoderms. Secondarily, an absolute increase in surface area devoted to food gathering could presumably support a larger theca. Development of additional arms could come about in two ways: bifurcation of the primary pair distal to the peristome or addition of wholly new arms at the peristome. In the latter case extra arms extending anteriorly are more probable since the external and internal water-vascular system, gonopore, and anus frequently are all posterior in position. The pentaradiate condition would originate from utilization of both alternatives; this would explain the bipentaradiate (2-1-2) appearance of the ambulacra of many echinoderms (Sprinkle, 1973: 42–43).

The Paracrinoidea exhibit a range of arm conditions demonstrating independent use of both mechanisms of arm increase. Two-armed genera (*Sinclairocystis*, *Amygdalocystites*, *Platycystites*, *Canadocystis*, and *Malocystites*) may have the arms either transversely or sigmoidally arranged; invariably they are dominantly or completely epithecal. The minority of genera with 3 or more arms (*Comarocystites*, *Oklahomacystis*, *Achradocystites*, and *Wellerocystis*) are evenly split between epithecal and exothecal forms. Three of the 4 definitely dichotomize 1 or both primary arms; *Achradocystites* apparently bifurcates the left arm, but so near to the peristome that the branch can be regarded as an independent third arm (Parsley & Mintz, op. cit., p. 15). *Oklahomacystis* also normally has 3 arms; the third results from a division of the left primary near the peristome.

Primacy in the Paracrinoidea of the transverse pair over a triradiate condition has not been conclusively established, largely due to the limited stratigraphic range and size of the class. However, the earliest paracrinoids, Chazyan in age, do possess only 2 arms. Neither Chazyan genus is likely to resemble closely the paracrinoid ancestor; *Malocystites* is "morphologically the most specialized genus the Paracrinoidea" (Parsley and Mintz, *op. cit.*, p. 90) and the thecal plates of *Canadocystis*, which lack a sutural pore system, are probably secondarily specialized (Parsley and Mintz, *op. cit.*, p. 57). In the absence of a lengthy geologic record other lines of evidence can be developed to reconstruct the class phylogeny. Study of morphological variants in large populations may be of use in this connection. If the overall trend in the Paracrinoidea was toward increased subvective efficiency, occasional 3-armed variant individuals in characteristically 2-armed species might be expected. The position of the third arm could provide data indicating either the biradiate or triradiate condition as ancestral. In the former case one would expect the additional arm to be anterior for the reasons cited above, but constancy of either position or point of origin is unlikely. If the triradiate condition were primitive, the third arm is not additional but recapitulates the ancestral condition. In this case the third arm should also be anterior in position but most likely would originate at the peristome rather than as a branch of one or the other transverse arms, and laterally it should be equidistant from both transverse members.

One 3-armed specimen of the usually 2-armed *Sinclairocystis praedicta* Bassler was mentioned by Parsley and Mintz (*op. cit.*, p. 43, pl. 3, figs. 9–10). The left arm of this specimen bifurcates near the peristome and the anterior branch of this arm is also divided near its end. Three-armed *Platycystites cristatus* Bassler have not been reported previously: the 2 specimens described below are in the collections of the Department of Geology, University of Iowa (SUI).

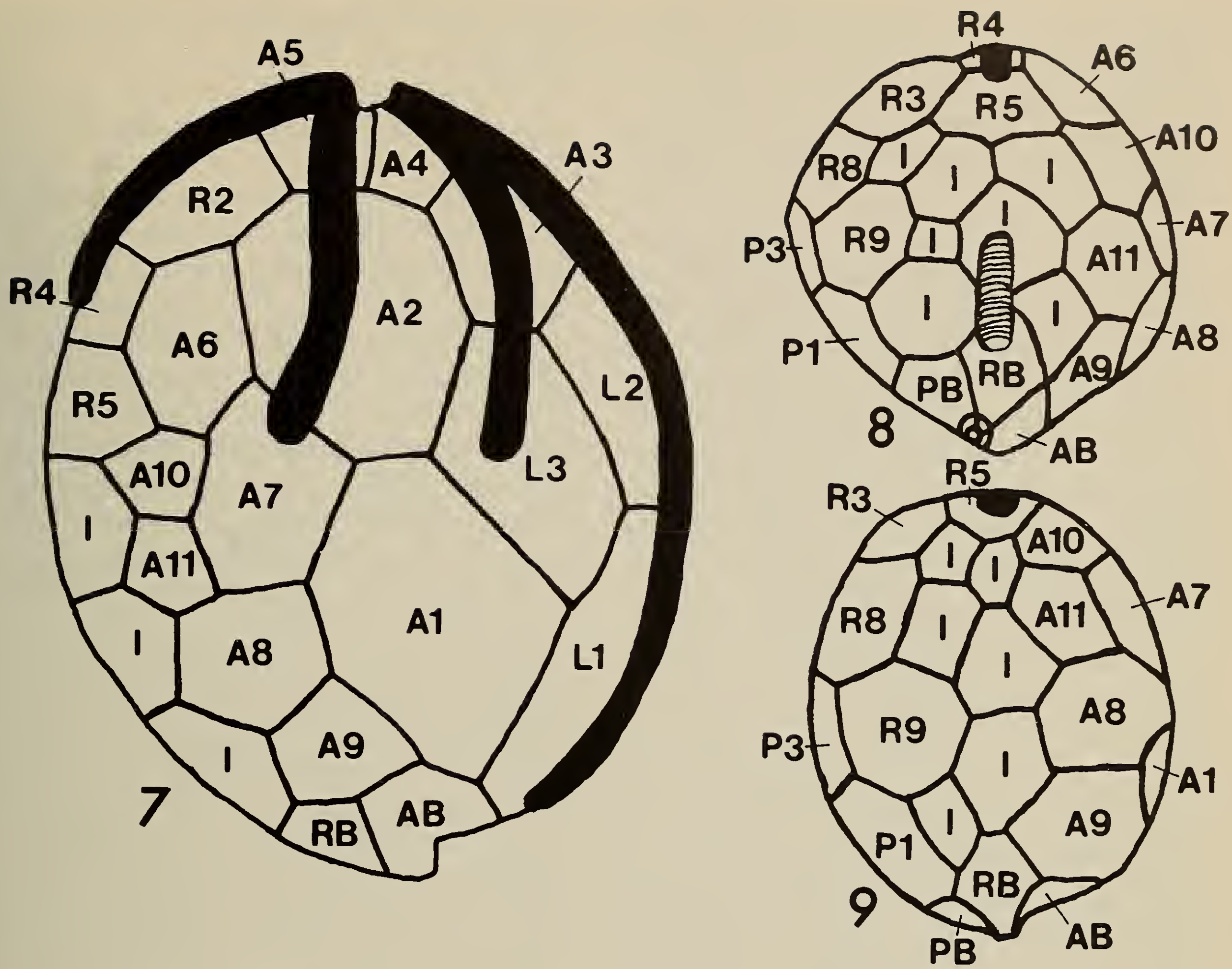
SUI 39518 is a large (diameter 32 mm) well-preserved specimen typical in all respects except in the possession of an extra arm (figs. 3–6). The third arm



Figs. 1–6.—Photographs of abnormal *Platycystites cristatus*. 1–2, basal and top views of SUI 39517 showing embedded stem and third arm, X2.7. 3–6, anterior, top, basal, and posterior views of SUI 39518, showing thecal morphology and arm configuration, X2.7.

arises from a bifurcation of the right primary near the peristome (fig. 4). Its length is approximately equal to that of the transverse right arm (17.8 mm). Calluses for all 3 arms are well developed and subequal in average width (fig. 3). The lumen is prominent in the vicinity of the peristome along the primary pair but does not extend into the third arm (fig. 4). From its origin immediately to the right of the peristome the third arm traverses A5 and A2 before curving onto A7, where it terminates. The point of termination is abrupt and lies just above the termination plane defined by the primary pair (fig. 7). A smaller specimen (SUI 39517: diameter 16 mm) also has a thecal plating arrangement within the normal range of variation for the species. Thecal shape in this specimen is somewhat distorted from the norm by the presence of part of an echinoderm column embedded in its right side (figs. 1, 8). A third arm results from a bifurcation of the left member of the primary pair on the anterior face. As in SUI 39518 the extra arm does not extend below the termination plane defined by the primary arms and is short, but well developed. The point where arm division occurs in this specimen is also near the peristome. An extension of the lumen into the third arm is present but is narrower and shorter than those in the other two arms (fig. 2). Beginning on A4 the anomalous arm intersects A3 and extends across L3 nearly to the A1-L3 junction before terminating (fig. 7).

Despite the small number of three-armed *P. cristatus* some reasonable inferences about the phylogenetic significance of the extra arm can be made. Both hypotheses (i.e biradiate vs. triradiate class radical) suggest that the third arm should be developed on the anterior face; this is the case for both *P. cristatus* and *S. praedicta*. Most of the evidence, however, is more in accord with Parsley and Mintz' hypothesized biradiate ancestor than with a triradiate one. The position of the extra arm is not fixed, it arises from a division of either member of the primary pair rather than from the peristome border, and it is not equidistant from the other arms. A well-developed lumen is not present; this is more consonant with the position that the third arm is additional, rather than a retained archaic feature. We concur with the suggestion of Parsley and Mintz that the need for a greater amount of subvective surface area leads to the acquisition of more than 2 arms in many paracrinoids. The paleoecology of *P. cristatus* is also supportive of this interpretation. Like Durham (in Parsley and Mintz, *op. cit.*) we believe that at least some species of *Platycystites* had the theca in contact with the substrate (Frest *et al.*, 1976). *P. faberi* Miller, which most likely was elevated above the sea bottom by its column, has both transverse arms nearly or exactly equal in length and extending nearly to, or even onto, the column. If the subvective system's area is closely related to arm length, *P. faberi* would have been more efficient in food gathering than *P. cristatus* due to its longer arms relative to thecal volume. The right arm of both *P. cristatus* and *P. infundus* is much shorter than the left. These 2 species are also more inflated in cross section than the laterally compressed *P. faberi*. We have suggested elsewhere (Frest *et al.*, *op. cit.*) that thecal asymmetry and broader thecas in some paracrinoids are adaptations to a recumbent habit (with peristome uppermost) and that shortening of the right arm in such forms is a mechanism to avoid fouling of the arm by sediment. The 2 genera in which 3-armed specimens have been reported both display this plexus of features. The advantages of a recumbent habit, especially less competition from other echinoderms, may have outweighed the disadvantages of a reduction subvective area; but it is probable, in our opinion, that the addition of a third arm was in part compensatory for the length loss suffered by the right arm in adaptation to a specialized environment. The recumbent habitus of some species may have en-



Figs. 7–9.—Plate diagrams of *Platycystites cristatus*. 7, composite showing positions of thecal plates and paths of epithecal arms (black). 8, right view of SUI 39517, showing thecal plate configuration and embedded column. 9, right view of typical specimen of *P. cristatus*, showing usual thecal plate pattern.

couraged arm incrementation over and above the general trend in the Paracrinoidea and other classes.

If the case presented herein for a primitive biradiate condition in the Paracrinoidea is far from conclusive, it is nonetheless suggestive. Demonstration of the phylogenetic antiquity of the "cystidean" transverse arm pair in at least 1 primitive echinoderm class (or subphylum, according to Parsley and Mintz) is strongly supportive of Ubaghs' postulated bilaterally symmetrical motile Precambrian ancestor for the Echinodermata (Ubaghs, 1968: S47) and further suggests that the primitive bilateral condition may have been maintained unaltered in some echinoderm classes, which would not have passed through a triradiate stage, as hypothesized by Caster (*in* Ubaghs and Caster, 1968; 1971). Both views assume an originally bilateral motile primordial form gave rise to all subsequent classes monophyletically some time before the beginning of the Paleozoic, but they diverge strongly on the origins and universality of the radially symmetrical strategy adopted by most later echinoderms.

Thus far most attention in attempts to resolve this problem has been focused on the "carpoid" classes (Subphylum Homalozoa), whose apparent bilateral symmetry, or asymmetry, has long been recognized. Ubaghs (*op. cit.*, 1969) believes that the primordial bilateral symmetry persists in the Homalozoa while Caster has argued that the carpoids are "*bilateralized* derivatives of a hypothetical tri-radiate (presumably sessile) ancestor" (Caster, 1971: 919). Most echinoderm classes have yet to be as thoroughly examined. Some classes undoubtedly do exhibit primitive triradiate symmetry (e.g. Edrioasteroidea: Bell, 1976).

Sprinkle (*op. cit.*, p. 42–43) has speculated that the change to a triradiate condition in the echinoderms was brought about by the development of a means of attachment and a plated subvective system early in the phylum's history. These 2 developments would also, according to Sprinkle, engender a modification of the subvective system toward radial symmetry, primarily as a response to the acquisition of a filter-feeding habit. Since the most fundamental adaptation was related to feeding, the subvective system would probably be the first to adopt the new pattern of symmetry. While this reasoning is plausible for most echinoderm groups it may not be applicable to all. Some paracrinoids (e.g. *Comarocystites*) were certainly attached to the bottom by a column and a stem facet, as contrasted with a holdfast (*sensu* Sprinkle, 1969: see also Sprinkle, 1973: 36–40), is present in all known species; but both Parsley and Mintz and we have presented evidence for the persistence in the Paracrinoidea of a bilaterally symmetrical transversely arranged subvective system in animals which had thoroughly adopted themselves to an attached, filter-feeding habit.

If, as we suspect, the sessile Paracrinoidea are fundamentally bilaterally symmetrical and have not passed through a radially symmetrical stage, it becomes more plausible that the triradiate stage is lacking in the ancestry of the Homalozoa as well. The existence of both sessile and motile non-radiate echinoderm classes indicates that the primordial condition may be more persistent than formerly believed, and perhaps is more widespread than currently accepted. Studies of symmetry patterns and deviations from them are lacking for most echinoderm classes, so that the functional and phylogenetic significance of both patterns cannot yet be adequately evaluated.

Paleoecology of *Platycystites cristatus*

Available evidence concerning the life-habits of *Platycystites* has recently been reviewed by Frest *et al.*, (*op. cit.*), who argue for a recumbent habit for *P. cristatus* and *P. infundus* but an erect habit for *P. faberi*. A single abnormal specimen of *P. cristatus* with an embedded echinoderm column provides additional evidence for a recumbent habit in this species. This specimen (SUI 39517) is also triradiate, as described above. The column fragment is embedded along the right side of the theca (figs. 1, 8) extending from RB onto the intercalate proximal to RB. The shape of the theca has been distorted somewhat in this area, presumably a response of the living animal to the column, but the plate configuration of the specimen is within the normal limits of variation in *P. cristatus*; a plate diagram of the equivalent area on a normal specimen (SUI 39516) is included for comparison (fig. 9). Several features of the specimen indicate that the stem became lodged in the theca during life. The column does not lie on the plates' surface, but is incised partly into the theca. During growth it has been laterally encroached upon and partly overgrown by the surrounding plates; the diameter at the best exposed end is greater than the exposed width of the column measured normal to its long axis. The involved plates are well-preserved, floor the groove underneath the stem as well as making up its walls, are clearly not fractured or broken, and appear to have been thickened proximal to the stem by secretion of secondary stereom. Plates of *Platycystites* are typically very thin and, one would suppose, not very resistant to deformation after death or during the fossilization process. The column itself is not as well preserved, and its identity cannot be established with certainty from its morphology as now known. Its position, nearly astride a line passing from the stem facet to the base of the right arm and upward to the peristome, may be taken to indicate that the column is that of the animal in which it is now embedded, but several lines of evidence militate against this conclusion. The stem portion is not precisely aligned as would be expected; an irregular flexure of the stem proximal to the facet would be required to connect the retained portion to the stem facet. The end most distant from the stem facet terminates in the theca and is poorly exposed. Proceeding from the stem facet, the embedded fragment becomes more deeply "buried." *Platycystites cristatus* columnals are generally much narrower than those of the embedded specimen (fig. 1). All 3 current interpretations of *Platycystites*' living position presuppose that at least the proximal part of the stem is functional throughout life; hence it should be as well-preserved as the adjacent, much thinner, thecal plates. We believe that the stem is a foreign object and not that of *Platycystites*; the alternative cannot, however, be categorically rejected on present evidence.

Review of the previously suggested paleoecologic interpretations in relation to this specimen allows a choice to be made among them regardless of the specific identity of the stem. Were the theca held erect (Parsley and Mintz model) a foreign object is unlikely to have become lodged in the theca's right side, which would be the exposed "bottom" (Parsley and Mintz, text-fig. 1), i.e. lowermost, but still considerably above the sediment-water interface. If the stem belongs to the specimen, the theca could not have been erect throughout its life span; one end appears to terminate in the theca. Even if the column did not terminate in such a manner, embedment would considerably impair the ability of the theca to adjust its position in this model and the animal would effectively have been fixed in a single position. Fixation of this part of the animal's stem would not greatly impede its operation if it functioned as an anchor (Durham model) or as a tether (our model). If the stem belongs to the theca and does normally terminate near the point exhibited by this specimen, function as an anchor is most probable among the three models. However Parsley and Mintz (*op. cit.*, pl. 8, figs. 1–3) do illustrate 1 specimen with a longer column. Alternatively it is possible that the stem became non-functional as the animal matured and the unattached negatively bouyant adult theca lay on or partly buried in the substrate, with the peristome uppermost. Assuming that the stem is a foreign object, the tether model becomes most likely true. A theca buried in a soft substrate is less likely to encounter or be damaged by a hard object than is a theca in contact with the substrate surface and perhaps capable of being moved over it by currents; but the point is not particularly telling. Overall inferences based on this specimen are supportive of either the anchor or tether hypotheses, but weigh heavily against the assumption of an erect habit in *P. cristatus*.

James Sprinkle (pers. comm., 1976) has suggested that the deposition of secondary stereom could indicate secondary repair of damage to an originally erect theca that has been "tipped over and injured . . . hanging on for dear life." While it is difficult to imagine how an accident with the observed results could happen to an erect theca, the possibility cannot be disregarded totally. Minimally, however, it suggests to us that a paracrinoid could survive recumbent on the sea bottom for a lengthy period of time—sufficient to allow extensive secondary secretion of stereom. Since the thecal shape has been influenced and there is no sign of plate fracturing around the embedded column we suspect that the column may have been encountered early in the animal's growth and did not greatly impede later growth or cause the animal's demise.

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Web-spinning eriophyid mites[1]

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ABSTRACT

The literature contains no mention of spinning among the Eriophyoidea; neither do anatomical studies suggest the presence of spinneretlike organs in this group of microscopic 4-legged mites.

Large colonies of an eriophyid mite, newly described as *Aculops knorri* Keifer, were encountered under weblike coatings on leaves of *Lepisanthes* (= *Erioglossum*) *rubiginosa* (Roxb.) Leenth. Attempts were made to determine whether the coatings are a host response to mite feeding or whether they consist of silklike strands emanating from the mite itself. Serological indications are that the strands, 0.3–0.6 μ wide, are proteinaceous in nature and are antigenically closely related to the mite. As far as known, these findings constitute the first report of spinning among the Eriophyoidea.

Although web spinning is common among many spiders and spider mites, it has not been recorded to occur among eriophyid mites. Neither have spinneret-like structures been detected in anatomical studies of these microscopic worm-like mites (Keifer, 1976).

Recently a report from the Sudan (Hassan and Keifer, in press) described

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a coating on mango leaves infested with the eriophyid *Cisaberoptus kenyae* Keifer. Incidentally, the same coating and mites are also found on mango in Thailand and the Indonesian island of Bali (Knorr, unpublished information). The coating is characterized as weblike, but the Sudanese report does not undertake to show that the covering is spun by the eriophyid.

The following account offers evidence that such webbing is not only associated with, but is the silklike product of, an eriophyid mite. This would thus constitute the first report of spinning among the Eriophyoidea.

On 16 April 1975, the first author encountered a sapindaceous fruit tree, *Lepisanthes* (= *Erioglossum*) *rubiginosa* (Roxb.) Leenth., at Bangkhen, Thailand with leaves exhibiting weblike patches (Plate II, figs. 1, 2, 3). Similar patches were later found in foliage of the same host at Hua Hin, 170 km to the south. A mango tree adjacent to the Bangkhen tree showed no webbing, although branches were intertwined with those of the web-bearing *Lepisanthes*.

Under the patches, but seldom outside of them, were large numbers of active eriophyids (Plate III, fig. 1), subsequently identified by Keifer (1976) as a new species, *Aculops knorri*. The only unusual feature found to distinguish the mite from others in this "wastebasket" genus was a thickening of the legs with most of the increased size on the femora (Plate I). No structures were seen that might suggest web-spinning organs.

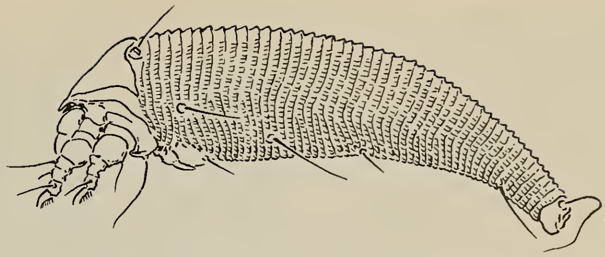

PLATE I: *Aculops knorri* Keifer, a web-spinning eriophyid mite. Length of female from anterior end of frontal shield lobe to end of terminal lobes, 128–148 μ.

Web Morphology

The weblike patches occur almost invariably on the adaxial surfaces of *Lepisanthes* leaflets. Patches are at first dull grayish white, resembling powdery mildew. In later stages, the webbing becomes shiny. The earliest visible trace of webbing approximates the size of a small pinhead; the largest expanse covers nearly the entire leaflet (Plate II, fig. 2). Elongate patches commonly border the main and lateral veins (Plate II, fig. 1). Incipient, pinhead-sized webs are often disposed without relation to veins. Webbing occurs throughout the canopy of this 25-ft tree with approximately 5% of the leaves affected.

Under 40× magnification and reflected light, the patches seem to be amorphous films although a suggestion of linearity appears at higher magnifications. With 1000× magnification provided by a scanning electron microscope, the films are clearly disclosed to be made up of fine criss-crossing filaments measuring 0.3 to 0.6 μ in breadth (Plate III, figs. 4, 5). Adjacent to this tangle of loose filaments, there is a consolidation of threads to produce what appears to be a woven or polymerized fabric (Plate III, fig. 5).

Between the patches and the leaf surface, the stereomicroscope at 40× reveals the presence of pale reddish-brown adults, water-white nymphs, and eggs of a homogenous population of eriophyid mites that are disposed uniformly beneath the webbing (Plate III, fig. 1). The occasional patch encountered on the underside of leaves contains the same mites, but even in old abaxial patches mites remain water-white in color. Mites are not particularly concentrated at, or aligned with, the peripheries of the patches. A young colony 0.5 mm in diameter generally contains 4 live mites. Larger concentrations of mites under the upper-surface webs can be made out with the naked eye as reddish-brown dots. Peak infestations and web formation occur from April to the beginning of the monsoon rains in

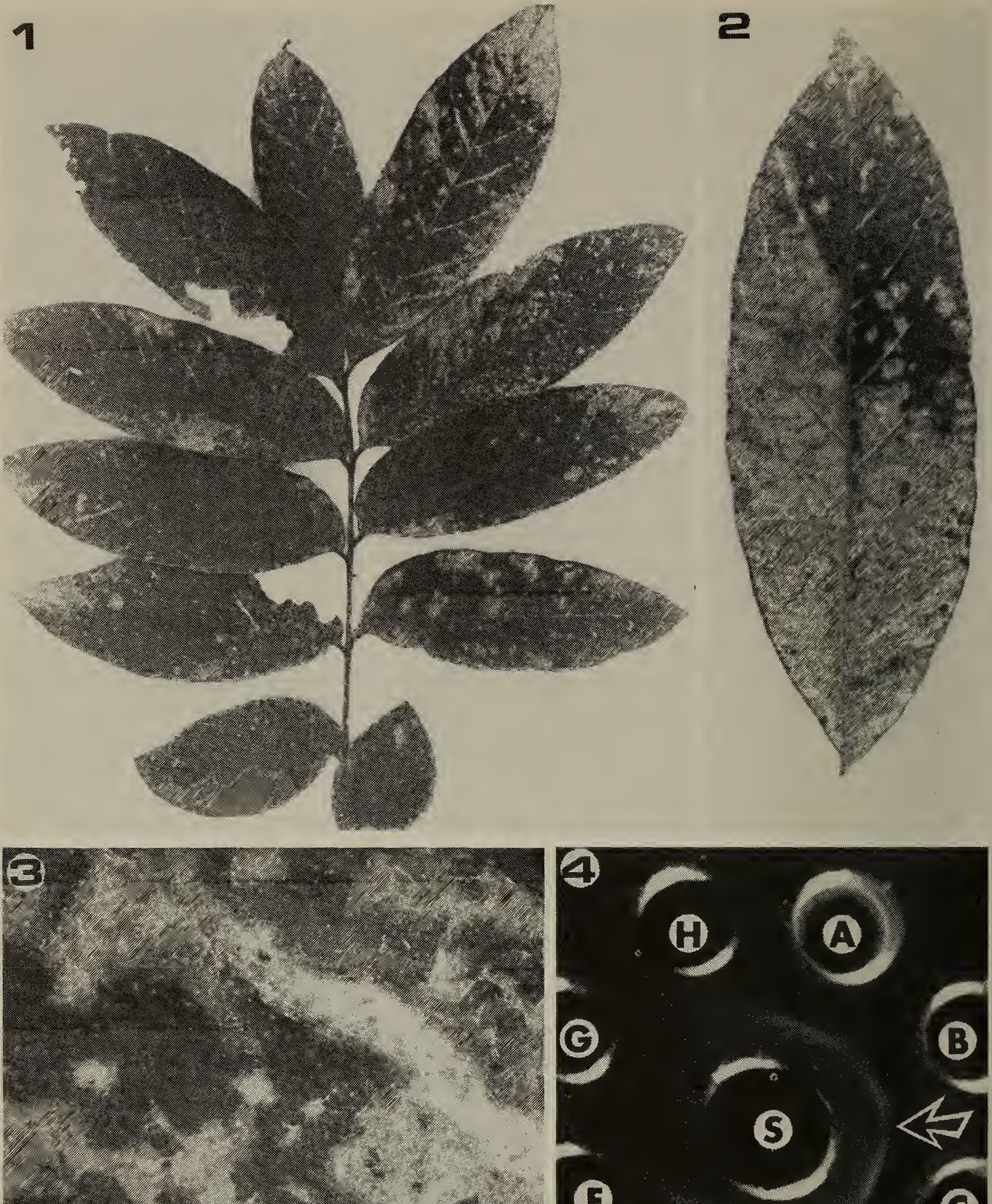

PLATE II: Figs. 1–4: 1. Entire leaf of *Lepisanthes rubiginosa* with eriophyid webbing. 2. Leaflet magnified. 3. Close-up of webbing. 4. Serological agar double-diffusion test for web antigens. Central well (S) in agar charged with antiweb rabbit serum; peripheral wells charged with: A and B, mite bodies in SDS-saline; C, D, and E, mite webbing in SDS-saline; F and H, host leaf scrapings in SDS-saline; and G, purified host leaf proteins in SDS-saline. Note opaque, white precipitation bands opposite all excepting the last 3 peripheral wells. The bands opposite B and C have fused (arrow) without spur formation.

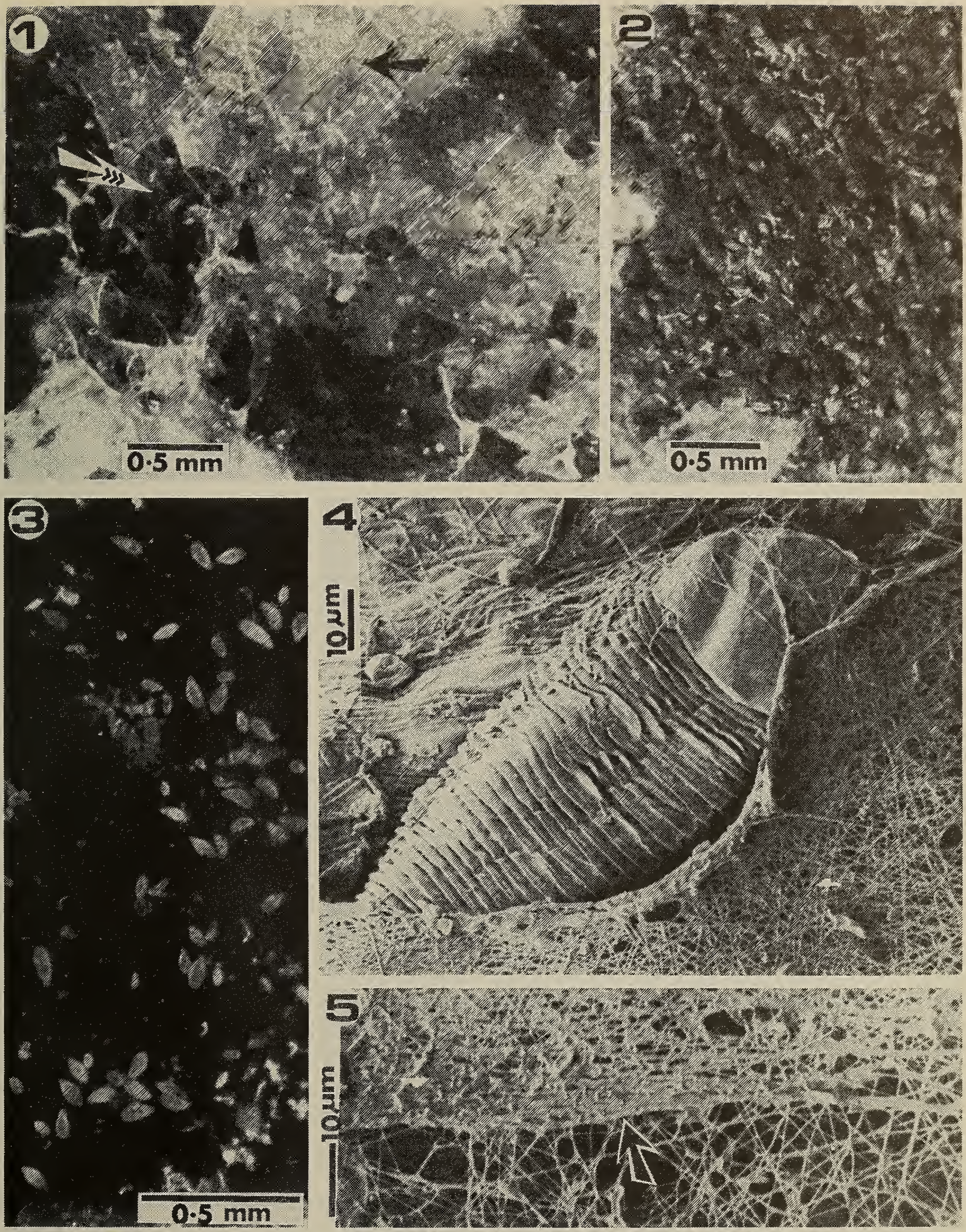

PLATE III: Figs. 1–5: 1. Increased magnification showing eriophyids underneath webbing (black arrow). Note reweaving of tear in original web (white arrow). 2. Webbing removed to show eriophyids in contact with leaf surface. 3. A scotch-tape water mount of eriophyids from Fig. 2. 4 and 5. Scanning electron micrographs of eriophyid and unconsolidated strands. In Fig. 5, note woven or polymerized strands (arrow) that form the fabric of the webbing. (SEMs courtesy of the Danish Technological Institute, Laboratory for Scanning-Electronmicroscopy, Copenhagen).

June. New leaves that flush after the start of the rainy season are apparently free of webbing, even after 1 month.

Though no systematic counts were made, there does not appear to be premature drop of affected leaves, nor do leaflets heavily coated with patches show any differences in growth when compared with adjacent uncoated leaflets. Under old patches, particularly alongside midribs and lateral veins, there is a slight russeting or necrosis of host epidermal tissues.

Web Composition

In the absence of any information in the literature that eriophyids spin, the weblike patches were first thought to represent a host response to feeding of the mites. A second possibility considered was that the *Aculops* mites on leaves of *L. rubiginosa* might inhabit webs spun by other mites, but whereas periodic observations over a year's time revealed the presence of *Brevipalpus phoenicis*, *Hemicheyletia* sp. near *bakeri*, *Cunaxa* sp., and *Phytoseius* spp., "none of these mites could cause the spinning associated with *A. knorri*" (E. W. Baker, in correspondence). Furthermore, at no time thoughout the year were webs found that were unoccupied by the spinning eriophyid. Two other eriophyids were found (*Acarhis lepisanthis* Keifer and *Hyboderus roseus* Keifer), but neither of these new species occurred on the upper sides of *Lepisanthes* leaves and neither was associated with webbing (Keifer, 1975). Consideration was also given to the possibility that the webbing might consist of waxy filaments, since it is known that certain eriophyids extrude wax.

A serological approach was taken to determine whether the webbing was a host artifact, a waxy secretion of the eriophyid, or a mite-secreted silk similar to the scleroproteinaceous filaments that make up the webs of spiders.

Serological Methods and Materials

Production of web immunogen.—Host leaves with apparently fresh webs and no other contaminants were collected on various occasions. They were washed with slow-running tap water to remove dust and debris, blotted gently with filter paper, and stored in a moist chamber until use the same day. Leaves infested with spider mites were rejected.

Leaflets with typical webs were examined under a low power stereomicroscope, and webs containing the fewest possible eriophyids were carefully teased free of adhering mites with a slightly blunted stainless-steel needle cleaned in 90% ethanol between use. In addition to excluding mites, care was also taken not to scratch the leaf surface so as to prevent contamination with host proteins. Several hours of work were required to obtain sufficiently concentrated web suspensions. The mite-free webbing was placed in a small volume of sterile distilled water. Although desirable, a photometric determination of web concentration was not made. The suspension was then poured into dialysis tubing, gently squeezed to break up the webbing, and dialized overnight against normal saline (0.85% NaCl in distilled water) in a refrigerator for the removal of any toxic substances. Dialysis was carried out for only the first injection into rabbits.

Production of antiweb serum.—A 2-year-old rabbit, weighing about 2.5 kg and reared under laboratory conditions, was used. Normal serum was collected a week before the first injection. The animal received 3.0 ml of the web suspension by the intravenous route on 31 October, 1975. It was followed by three injections of 2.0, 2.3, and 1.5 ml suspensions respectively, on 4, 5 and 6 November. Four more intravenous injections of 1.2, 2.2, 2.0, and 2.0 ml were given to the same animal on 10, 12, 13, and 14 November, respectively. Thus, 16.2 ml of web suspension were injected in 8 instalments within 15 days. The animal was bled 4 days after the last injection and a 20 ml sample of blood was collected. The blood was allowed to clot for 2 hours at room temperature followed by refrigeration overnight. The clot was broken with a glass rod, the serum de-canted and then centrifuged for 15 min at 3000 rpm to remove corpuscular matter. Sodium azide was added to the antiweb serum as a preservative at final concentration of 0.03% and the serum stored at about −15°C.

Serological tests.—A gel of 0.8% Ionagar No. 2 (Colab, USA) containing 0.5% sodium dodecyl sulphate-SDS (Sigma, USA) was made in normal saline solution by autoclaving at 120°C, 15 psi pressure, for 10 min. Sterile petri dishes (100 mm diameter) were poured with 10 ml hot agar containing 0.02% sodium azide, which was allowed to solidify. Using a flame-sterilised cork borer (No. 2, 4 mm), test patterns were cut in agar in the form of 6 or 8 peripheral wells around a slightly larger (5 mm) central well cut with No. 1 cork borer. Distance between closest edges of the central and the peripheral wells was 5–7 mm. Agar plugs were removed with a pipette connected to a vacuum line. Generally, 3 sets of 7 or 9 wells each were produced in 100-mm petri dishes. Undiluted antiweb serum was placed in the central well while peripheral wells were charged with (1) pure web suspension in saline, with or without1, 2, or 3% SDS, (2) eriophyid mite bodies in saline, with or without SDS, (3) scrapings from the upper surface of host leaves in saline, with or without SDS. Controls were of normal saline and SDS at the 3 concentrations, and normal serum against all above treatments. After charging the wells, the petri dishes were maintained in a humid chamber at room temperature up to several days and observed daily in transmitted, oblique lighting.

Results.—Positive reactions in the form of characteristic white, opaque precipitation bands were observed within 48 hr between the antiserum-containing central well and the peripheral wells carrying web suspension with SDS, as well as those charged with mite bodies with SDS, but not the wells containing host scrapings with or without SDS, even after several days of incubation (Plate II, fig. 4). Also, there were no reactions with any controls. Precipitation bands were absent when normal serum was tested against any of the treatments—web, mite, or host scrapings. The extent of positive reactions of the antiweb serum with webs and mite bodies was comparable.

Discussion

Since utmost precaution had been taken to avoid contamination of the web preparations used for immunization, the positive serological reaction of mite bodies with antiweb serum indicates relationship between the web and the mite. Also, the immunogenicity of the web is evident. The similarity of the positive reaction of the web and the mite bodies suggests that the latter share all or nearly all antigen species with the former. Absence of reaction with host scrapings at the same time indicates lack of any such relationship between the web and the host leaf.

An alternate hypothesis was that the webbing might consist of mite-secreted wax. On the basis of serological evidence, this now appears untenable since waxes are not known to be immunogenic.

In order to confirm nonexistence of a host relationship, it was considered advisable to repeat the test with concentrated proteins from the host foliage. The work was conducted following the method of Shepard (1972). Young as well as mature green leaves of *L. rubiginosa* were collected free from mite infestation and macerated in a Waring blender with ice-cold 0.5 M borate buffer, pH 8.2, containing 1% sodium sulfite and 0.01 M magnesium acetate at the rate of 3 ml buffer/g of foliage. The macerate was filtered through a layer of cheesecloth and shaken with cold chloroform (1:1 by volume) for 30 min. The preparation was centrifuged at 10,000 *g* for 10 min and the aqueous phase recentrifuged at 80,000 *g* for 90 min. After discarding the supernatant, the pellets were suspended overnight in 1/30th the original volume of 0.05 M Tris buffered-saline, pH 7.2, containing 0.01 M magnesium acetate. The protein preparation obtained by this method was tested, with and without dilution and SDS, against the antiweb serum, but there was no reaction.

It appeared that soluble protein species are either lacking or are in too low concentrations to be detected by the gel diffusion test, in web suspension as well as in mite-body suspensions. Perhaps that is why there was no reaction when SDS was not used. There have been reports on the use of SDS for degrading filamentous plant virus particles for easier diffusion in agar gel (Gooding and Bing, 1970; Purcifull *et al.*, 1973, 1975). In the present work, 3% SDS tended to produce nonspecific turbidity in agar, and subsequently only 1% SDS was used for degrading presumably large molecules of web proteins as well as mite-body proteins into diffusable antigens.

The similarity in the extent of positive reaction of web suspension and mite-body suspension against antiweb serum is not surprising if we accept that the mite produced the webs. In that case the web antiserum would be expected to have antibodies against antigen species common to the web and the mite. On the other hand, an antimite serum would have given different qualitative as well as quantitative responses against the mite and the web. Reciprocal testing with antisera against mite-body proteins and against normal host proteins would have been desirable but has not been done. Nevertheless, there is a strong indication that the eriophyid mite on *L. rubiginosa* is involved in the production of proteinaceous webs associated with it.

Ultimate proof that the mite actually spins must come from direct observation. Efforts to demonstrate this have so far not succeeded owing to the difficulty of visualizing *in situ* the emanation of strands only ⅓ μ wide. Neither have attempts yet succeeded in transferring mites to clean leaf surfaces in order to observe web construction. There is, however, evidence of reconstruction in Plate III, fig. 1, where tears in the original web have been rewoven. Repair takes place only when the mites are present.

The function of the webbing may conceivably be to afford protection to the spinning eriophyids. Though several species of predaceous mites were found in conjunction with the webbing, no predation of *Aculops* mites happened to be observed. Protection is more likely against the washing effects of rains. The anchoring function seems borne out by the virtual non-establishment of webs on leaves emerging after onset of the monsoon rains.

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Notes on Tadpoles as Prey for Naiads and Turtles

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Although there is a large literature on predator-prey interaction theory, there are still some specific interactions for which there is little or no information. Naiads and turtles are known predators on tadpoles, but nothing is known concerning feeding rates involved. In order to gather some basic information on these specific interactions, we ran some simple, straightforward experiments while on Barro Colorado Island, Canal Zone, in July 1975.

Naiad-Tadpole Experiments

The purpose of the experiments was to determine the maximum feeding rate of naiads, using tadpoles as prey. All experimental animals, plants and water came from a cement pond in the living compound built by A. S. Rand for his studies on *Physalaemus pustulosus*.

Holding and experimental containers were square or round plastic containers approximately 9 cm across, filled with pond water 4 cm deep. Large naiads (Family Libellulidae, *Orthemis* sp. prob. *ferruginea*) were isolated for 1 or 2 days prior to introducing them to the prey. Each experimental tray had 1 naiad, some water weed (*Hydrella*), and a superabundance of prey, either 30 or 50 individuals, depending on prey type. Three types of prey were used: 30 small *Agalychnis callidryas* tadpoles, 50 small *Physalaemus pustulosus* tadpoles, or 30 large *Physalaemus pustulosus* tadpoles. Experiments were run from 22-¾ to 26-⅔hr. Other projects did not allow exact 24-hr experimental runs in all cases. All tadpole larvae were well within the size range on which the naiads could feed. At the end of each experiment, the naiad and remaining prey were preserved together in a vial containing 10% formalin. Five replicates of small *Agalychnis*, 10 replicates of small *Physalaemus*, and 12 replicates of large *Physalaemus* were run. In one of the small *Agalychnis* runs, several tadpoles died in handling; the results of this particular run are not included in the analyses.

In the laboratory, the following data were taken from specimens in each experimental vial: 1) the number of tadpoles left after the experiment; 2) the volume of the tadpoles left after the experiment, 3) the volume of the naiad. Volumes were determined by formalin displacement in a 10-ml graduated cylinder. Excess surface moisture was removed by paper towelling before volume determination. From these data, the following were determined: 1) the number of tadpoles consumed during the experiment (initial number minus number left), 2) the volume of tadpoles eaten per predator adjusted to 24 h. The assumption used in determing this last value is that the sizes of the tadpoles consumed were the same as the sizes of the tadpoles left in each experiment. As post-hatchling *Agalychnia* and large premetamorphic *Physalaemus* were used, the size variances in experiments using these prey were not great. The greatest size variance was in the experiments run with small *Physalaemus* as prey.

The data were analyzed using the UCLA Biomedical 10V program (Dixon, 1974), general linear hypothesis without and with a covariate, testing numbers of prey and volumes of prey consumed separately.

The results of the analysis testing kinds of prey based on numbers of prey eaten are presented in Table 1. There is a signif-

TABLE 1.—Analysis of number of prey types eaten with no covariate. P1 = *Agalychnis*, P2 = Small *Physalaemus*, P3 = Large *Physalaemus*. SS = sums of squares, DF = degrees of freedom, MS = mean squares, * = significant at the 5% level, ** = significant at the 1% level.

Source	SS	DF	MS	F
Prey	221.86145	2	110.93072	4.92604*
P1 = P2	31.77779	1	31.77779	1.41114
P1 = P3	27.75521	1	27.75521	1.23251
P2 = P3	221.79206	1	221.79206	9.84900**
Error	517.94317	23	22.51926	

icant difference in the number eaten among the 3 prey types and the difference is between the number of small *Physalaemus* vs. large *Physalaemus* eaten.

The results of the analysis testing kinds of prey based on volumes of prey eaten are presented in Table 2. There are no significant differences among the volumes eaten of the 3 prey types.

Large naiads were purposely chosen to minimize the variation in the experiments due to predator differences. Predator-prey size relationships are very important, however (e.g. Heyer *et al.*, 1975), so the data were tested to see if the results were affected by differences in sizes among the predators. To test, volume of predator was used as the size factor and included as a covariate with the data as analyzed in Tables 1 and 2. The results with the covariate added are presented in Tables 3 and 4. The results are exactly the same as in Tables 1 and 2; size differences among the predators used had no effect on the experiments.

The average number of *Agalychnis* consumed per naiad over 24 h is 5.7 with an average volume of 0.038 ml/tadpole. The average number of small *Physalaemus* consumed per naiad over 24 h is 9.0 with an average volume of 0.027 ml/tadpole. The average number of large *Physalaemus* consumed per naiad over 24 h is 2.63 with an average volume of 0.109 ml/tadpole. An individual naiad consumed 0.77 of its volume in prey tadpoles per 24 h on the average.

Turtle-Tadpole Experiment

A single 49.5-mm-carapace-length juvenile turtle, *Chrysemys scripta*, was found in Rand's pond. After isolating the turtle for 24 h, it was placed in a plastic container of the same size as used in the naiad experiments, without water weed, and with 30 large *Physalaemus*. After 26-⅔ h, all of the tadpoles had been killed and at least partially consumed. The water was turbid. After isolating the turtle for 24 h, it was placed in the bottom of a plastic Chlorox bottle from which the top half had been cut off. The bottle was 15 cm in diameter and water was placed 4 cm deep. Some *Hydrella* was added along with 30 large *Physalaemus*. We were interested in knowing if giving the prey a better opportunity to hide from the predator would make a difference in the results. After 26.5 h, only 1 tadpole was left alive. The water was clear. The turtle was isolated for another 24 h. The experimental setup was the same as the previous run except 100 large *Physalaemus* were added. After 27 h, 1 *Physalaemus* was left alive. The water was relatively clear. The turtle was isolated for 48 h. The next experiment differed only in adding 200 large *Physalaemus*. After 25-⅓ h, 71 *Physalaemus* were alive, but the water was dark brown as in the first run. As turtles are largely visual feeders,

TABLE 2.—Analysis of volume of prey types eaten with no covariate. See Table 1 for explanation of abbreviations.

Source	SS	DF	MS	F
Prey	0.08021	2	0.04011	0.63027
P1 = P2	0.07498	1	0.07498	1.17833
P1 = P3	0.06235	1	0.06235	0.97984
P2 = P3	0.00173	1	0.00173	0.02726
Error	1.46360	23	0.06363	

TABLE 3.—Analysis of number of prey types eaten with naiad volume as a covariate. See Table 1 for explanation of abbreviations.

Source	SS	DF	MS	F
Prey	211.99865	2	105.99932	4.52292*
P1 = P2	32.59413	1	32.59413	1.39077
P1 = P3	29.91784	1	29.91784	1.27657
P2 = P3	211.99650	1	211.99650	9.04575**
Covariate	2.35026	1	2.35026	0.10028
Error	515.59291	22	23.43604	

the limits of the experimental design had been reached.

Discussion

A model has been proposed recently which attributed a limiting factor of tadpole diversity to fish predation (Heyer *et al.*, 1975). The same authors commented that other vertebrate predators may also control tadpole diversity through completely eliminating tadpole populations in given ponds. Such invertebrate predators as dragonfly larvae were considered not to be able to eliminate tadpole populations, although tadpole populations could be markedly reduced. The critical aspect is elimination, not reduction of tadpole populations.

Although Rand's pond from which all experimental animals were taken is artificial, the assemblage of species in it probably is not. For purposes of discussion, then, only the species populations in this pond will be examined. There are two aspects to eliminating tadpole populations; eliminating the tadpoles from a single clutch of eggs and eliminating the total tadpole population, which would result from 1 or more clutches of eggs. The average of 16 *Agalychnis* egg clutches counted was 53.4; of 3 *Physalaemus* nests counted, 216.7.

TABLE 4.—Analysis of volume of prey types eaten with naiad volume as a covariate. See Table 1 for explanation of abbreviations.

Source	SS	DF	MS	F
Prey	0.08164	2	0.04082	0.63759
P1 = P2	0.08159	1	0.08159	1.27454
P1 = P3	0.03877	1	0.03877	0.60558
P2 = P3	0.01371	1	0.01371	0.21413
Covariate	0.05517	1	0.05517	0.86185
Error	1.40843	22	0.06402	

The turtle, *Chrysemys scripta*, could possibly eliminate the tadpoles from a clutch of *Agalychnis* eggs in about 0.5 day, and the tadpoles of a *Physalaemus* clutch in somewhat more than 1 day. By remaining in a pond for a few days, *Chrysemys scripta* could theoretically eliminate the tadpole population from the pond, assuming moderate anuran reproductive output. Whether turtles remove entire tadpole populations in nature remains to be determined, however. There is at least one reason to believe that turtles would not eliminate tadpoles. Turtles are mobile feeders; as the tadpole population is reduced, the energy spent in capture becomes greater. There is likely a point where the energy expenditure per capture becomes so great that the turtle switches to another prey, if available. The experimental evidence presented here suggests that turtles can be effective tadpole predators, even if turtles do not completely eliminate tadpole populations.

If the average consumption rates of the large naiads are used together with average clutch size, it takes A) 9.4 large naiad days to consume the small tadpoles from a single *Agalychnis* clutch; B) 24.1 large naiad days to consume the tadpoles from a single *Physalaemus* clutch if the tadpoles are consumed when small; C) 82.4 large naiad days to consume the tadpoles from a single *Physalaemus* clutch if the tadpoles are consumed when large. These are probably maximal rates, as the experiments were designed to saturate the predators with prey.

From these data, it would appear that

a small population of large naiads could eliminate *Agalychnis* tadpoles from a pond. The experiments did not take habitat differences into account, however. The experimental trays were small enough that the naiad could sample tadpoles from the entire water volume, as there was enough *Hydrella* in the trays to allow this. In the pond from which the experimental animals were taken, the naiads were either sitting camouflaged on the cement edge or in *Hydrella* mats. The *Agalychnis* were in the open water; the *Physalaemus* appeared to be everywhere. Thus, the naiads and *Agalychnis* tadpoles were effectively spatially isolated. Another factor contributing to the likelihood that naiads would not eliminate *Agalychnis* tadpoles from ponds relates to size. *Agalychnis* hatchlings are large and the tadpoles become much larger than *Physalaemus* tadpoles. Large *Agalychnis* tadpoles are too large for the size naiads used in the experiments to feed upon (also see Heyer *et al.*, 1975). Thus, in nature, we would not expect naiads to regularly eliminate *Agalychnis* tadpoles from ponds.

The *Physalaemus* larvae are always within the size range of prey items for the size of naiad used in the experiments, and the tadpoles and naiads occur in the same pond habitats. The ingestion rates suggest that the *Physalaemus* tadpoles would not be eliminated by naiads, however. The duration of the *Physalaemus* larval stage probably does not exceed 30 days and small *Physalaemus* larvae would grow to large larvae within 2 to 3 weeks. In terms of a clutch, then, even with maximum naiad predation, some larvae would avoid predation and become large larvae; once the *Physalaemus* larvae are large, the rate of predation falls markedly, such that some larvae would make it through to metamorphosis.

The naiad evidence presented here, while not conclusive, is consistent with the hypothesis that under usual conditions, naiads will reduce—not eliminate—tadpole populations. This was certainly true in the pond from which the experimental animals were taken. There was a noticeably present naiad population, many *Agalychnis* tadpoles and an abundance of *Physalaemus* tadpoles. Assuming that naiads were consuming tadpoles in the pond, the tadpoles were not eliminated; many made it through to metamorphosis during the time we observed the pond.

Under unusual conditions, when the numbers of naiads per volume water is greater than usual, and pond microhabitat differences disappear, the data presented here suggest that naiads could eliminate tadpole populations. Such conditions can occur when temporary ponds dry up as have been reported from field situations (Heyer, 1973).

Another important factor to consider is the nutritive value of tadpoles. Tadpoles are feeding machines, and an unusually large part of the volume of a tadpole is gut. The gut contents, usually algae and diatoms, are not digestible by many tadpole predators, so the total food value of a tadpole to its predator is effectively much less than of a similar sized fish, for example (R. T. Lovell, pers. comm.). Thus, particularly for vertebrate predators, tadpoles may be consumed only when they are very abundant relative to other prey items. The avoidance of tadpoles as prey might involve a tast preference as the gut contents of the tadpole may be distasteful.

One aspect of the experiments invites speculation. The results indicate that naiads feed until they are full, irrespective of the number of prey items it takes to fill them. It would be interesting to know the relative energy costs of naiads catching 9 small *Physalaemus* vs. 3 large *Physalaemus* per day. There are two energy costs to a naiad in consuming prey: 1) the cost of discharing the catching apparatus and trapping the prey (fixed energy cost due to the mechanism involved), 2) the cost of manipulating the struggling prey back into the mouth to be eaten (variable cost). If the latter energy cost is the same for small and large *Physalaemus*, then a naiad would clearly benefit energywise by concentrating on larger prey items. If large struggling tadpoles take much more energy to manipulate into the mouth than small tadpoles, then a naiad would benefit in an energy budget by concentrating on smaller prey items. To our knowledge, the relative energy budgets involved in prey capture by naiads are unknown.

Acknowledgments

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Notched Teeth from the Texas Panhandle

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ABSTRACT

Mutilated human teeth from prehistoric North America have previously been reported from relatively late prehistoric sites in areas of well-known Mesoamerican influence. Recently 2 examples of probably filed teeth have been found in sites from the Texas Panhandle, an area not known for Mesoamerican influence. In addition, the skeletons could be considerably older than those previously reported, perhaps from the Archaic period.

The presence in prehistoric Mesoamerica of a wide-spread custom of tooth mutilation involving various types of notches and grooves has been known for a long time and now is well documented (Romero, 1970). However, not until 1944, when a series of 4 articles began appearing in this *Journal*, was clear evidence presented that the custom had made its way into prehistoric America north of Mexico. Although there was an early mention of the finding of notched teeth at Sikyatki Pueblo, Arizona (Saville 1913: 378, footnote 1), Campbell (1944) was the first to describe the teeth in full. The same year Stewart and Titterington reported 1 labially grooved and several occlusally notched teeth from Cahokia and vicinity in Illinois. Additional examples were described later from Macon, Georgia (Stewart and Titterington, 1946: 259–260), the Dickson Mound in Illinois

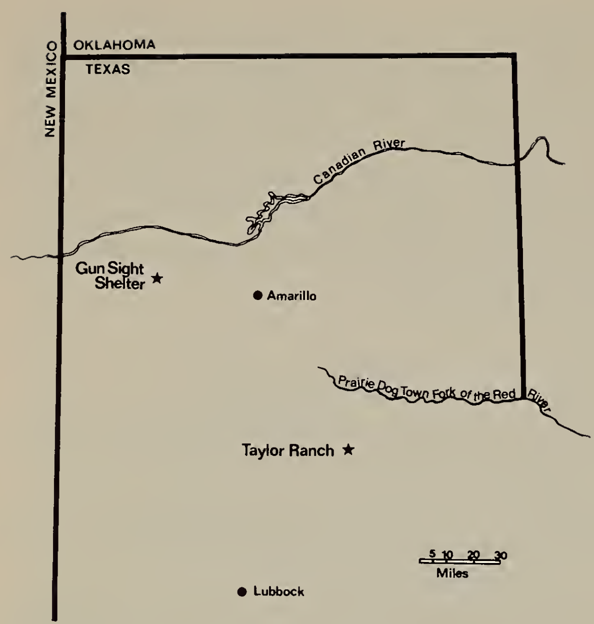

Fig. 1.—Texas Panhandle showing the locations of the Taylor Ranch Site and Gun Sight Shelter.

(Stewart and Titterington, 1946: 260–261), the Rees Site near Cahokia, Illinois (Holder and Stewart, 1958: 349–356), and from Cahokia itself (Holder and Stewart, 1958: 356). Stewart summarized all these finds in his book (1973: 193), noting that they all came from archeological contexts, suggesting a late prehistoric time period and substantial Mesoamerican influence.

As one might expect, the highly visible anterior teeth are those most often modified. Among the specimens described in the publications mentioned, the central incisors are most common, the lateral incisors next most common, and the canines least common (actually only 1 has been reported). The mutilations thus far reported are of the simplest of forms: 1 or more V-shaped notches filed into the occlusal surface and/or a transverse labial groove. The labial groove is easily confused with defective enamel resulting from hypoplasia.

Recently 2 Indian skeletons with notched teeth were recovered through the careful excavation of 2 different burials in the Texas Panhandle, an area with no other evidence of direct Mesoamerican influence. In addition, both discovery sites possibly date from the Archaic Period, which, if confirmed, would add considerably to the known antiquity of the custom in North America. Our purpose here is to present the provenience, description, and implications of the new finds.

Taylor Ranch Burial

The Taylor Ranch Burial (Panhandle-Plains Historical Museum Site A-1063; Burial 1) was found about Christmas 1972 by the ranch-owner, Walter Taylor, 6 air mi southwest of Quitaque, Texas (Fig. 1). Taylor and his daughter partially excavated the burial in July 1973 and then notified Dr. Jack T. Hughes, Department of Geology and Anthropology, West Texas State University, Canyon, and Mr. Billy R. Harrison, Panhandle-Plains Historical Museum. On July 27, 1973, Hughes and Harrison (Hughes' field notes for that date filed with the Panhandle-Plains Historical Museum) were given the bones already removed (left arm, leg, innominate, and scapula), were guided to the burial location, and were allowed to expose and remove the rest of the burial. The bones were removed in clumps which included the dirt matrix and were transferred to West Texas State University, where in November of 1974 they were processed by a field archeology class under the direction of the first author. It was then that the notched incisors were discovered by Mr. Billy Pat Newman, a student in the class. The skull and mandible were shipped to the second author for inspection but were later returned and are now housed in the Panhandle-Plains Historical Museum.

According to Hughes (field notes), the burial was exposed in the side of a deep sinkhole (Fig. 2) in a colluvial bench of North Pole Creek. The sinkhole occurred where the colluvial bench joined a bedrock cliff at the neck of a long narrow meander, and in all probability the 40-yard-long sinkhole was caused by underground drainage across the neck of land. The bench consisted of a compact light pink sand colluvium which, as indicated by the sinkhole's profile, was at least 24.5 ft thick. The skeleton was exposed in a vertical side of the sink 12.5 ft from the bottom of the hole, 12 ft from the top, and although the pit was not clearly delineated, the skeleton was most likely buried from a surface 2.5 ft above the bottom of the grave. Above the pit bottom 1.9 ft were two large sandstone slabs, the most common rock in the area (Fig. 3), and at 2.5 ft a smaller sandstone rock seemingly indicated the surface from which the grave was dug. The surface was vaguely marked there and elsewhere in the exposure by a line of differential erosion. Both below and above the old surface, the colluvium was massive, suggesting rapid accumulation both before and after the formation of the old, weathered surface. However, this rapidly accumulated colluvium does not rule out considerable antiquity of the burial. Hughes (personal communication) believes the burial is probably Archaic, although this

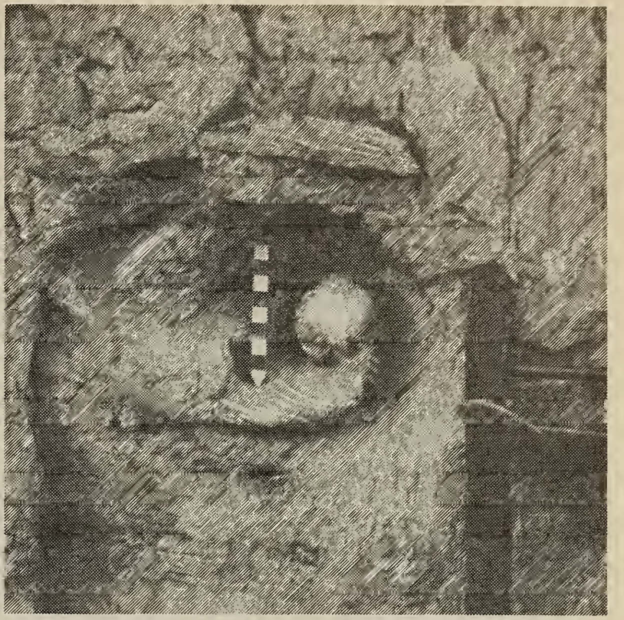

Fig. 3.—Taylor Ranch Burial. Note the 2 large sandstone slabs above the skeleton and above them a line of differential erosion which apparently indicates the surface from which the grave was dug. View is south. Photograph courtesy of Jack T. Hughes.

Fig. 2.—Partially excavated Taylor Ranch Burial in side of sinkhole. The skeleton is approximately 12 ft from the top and 12 ft from the bottom of the sink. View is to the southwest. Photograph courtesy of Jack T. Hughes.

antiquity is difficult to prove due to the lack of associated artifacts.

The skeleton was apparently placed in a small oval-shaped, shallow pit, measuring 2.25 ft east-west, at least 1.25 ft north-south, and as noted above, probably 2.5 ft deep. The individual was lying on its back, legs tightly flexed upward and to the left, arms semi-flexed with the hands near the pelvic region, head to the west but facing southeast (Fig. 4). In addition to the 3 sandstone rocks mentioned above, 5 burned sandstone cobbles were on top of the chest and pelvis, a Tecovas jasper flake was south (right) of the pelvis, and several small shells (*Succinea*?) and scattered charcoal flecks occurred throughout the pit-fill. The sandstone cobbles were likely intentionally interred with the person; the flake, shells, and charcoal may have been there fortuitously. Other than the depth below ground level, the burial is like many other Indian interments from the area.

The bones of the Taylor Ranch Burial are in a fair state of preservation; most of the bone shafts are intact, but the ends are commonly missing and none—even those reconstructed—is complete.

Fig. 4.—Close-up of the Taylor Ranch Burial *in situ*. The skeleton is lying on its back, leg flexed upward and to the left, head to the west but facing southeast. View is to the south. Photograph courtesy of Jack T. Hughes.

All bones are stained pink, typical of the effects of extended contact with the red Triassic or Permian soils or soils derived from either of these. Isolated charcoal stains occur on 2 cervical vertebrae, the greater trochanter of the left femur, and the left fifth metatarsal. Rather than being the marks of *in situ* burning, the charcoal stains appear to represent sites of contact with small charcoal pieces in the soil since the marks are small, homogeneously colored, and do not penetrate to the interior cancellous bone.

The skull was recovered intact but came apart during cleaning. It was easily repaired with minimum warpage. In addition to the skull and mandible, most of the other major bones are represented including parts of all major limb bones (except the left humerus) as well as many bones of the hands, feet, chest, and pelvis. There are no indications that more than 1 person is present.

The skeletal remains suggest a female. The pubic region, sciatic notch, femur head diameter, and the general lack of robusticity all support this identification.

There can also be little doubt concerning the race of the individual. The shovel-shaped incisors and flat face suggest that the person was Mongoloid. These morphological observations coupled with inferences made from the archeologic and geologic contexts indicate the person was American Indian.

Age was estimated from the degree of epiphyseal union, suture closure, pubic symphysis change, and tooth wear. All of the criteria indicate a person in the 16 to 22 yr age range with the exception of Gilbert and McKern's method for female pubic symphysis aging, which suggested a greater range but include the years mentioned above. This last method is most appropriate for aging older females.

All teeth are present except the left maxillary third molar and both mandibular third molars which appear to be congenitally missing. All teeth display some crown loss due to attrition, especially the first molars. Notches occur in the center of the labial incisal edge of the mandibular and maxillary central incisors (Figs. 5, 6). The notches are V-shaped, located centrally in the maxillary incisors and slightly right of center in the mandibular incisors. In all cases the borders of the notches are clear-cut and sharply defined. The notches on the mandibular teeth are slightly closer together than on the maxillary teeth. Thus with the mandible and maxilla in occlusion, the notches do not exactly match. Also the paired notches themselves do not correspond in size. Both maxillary notches are much wider than those of the mandible. Originally the notches may have been more apparent since the incisor crowns have been reduced at least 1 millimeter by attrition.

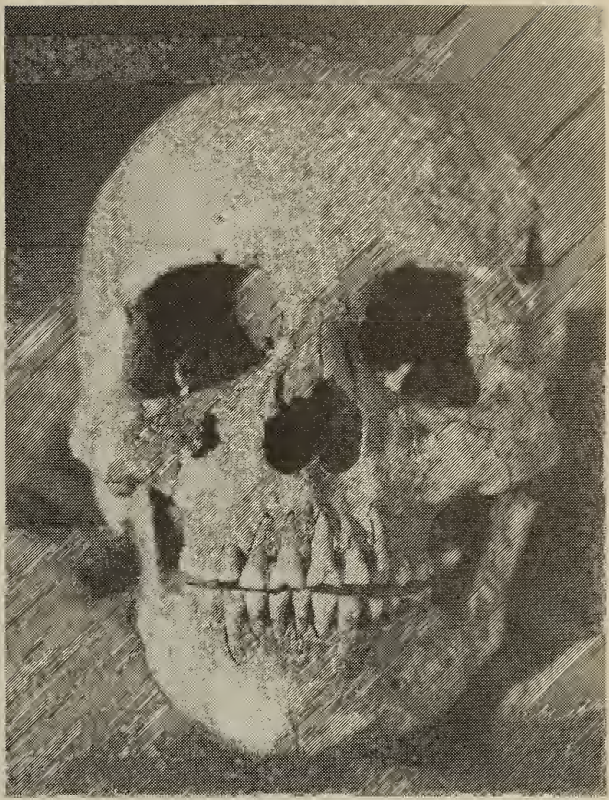

Fig. 5.—Front view of the Taylor Ranch skull and mandible showing the notched teeth. The skull is not oriented in the Frankfort Plane.

Burial From The Gun Sight Shelter

The Gun Sight Shelter, (Panhandle-Plains Historical Museum Site A-1203), located near Vega, Texas (Fig. 1), was excavated by Mr. Billy Ray Thompson of Amarillo, Texas. He is affiliated with the Panhandle-Plains Historical Museum in Canyon, Texas, and performed most of the work with volunteer amateur archeologists during the spring and summer of 1974. The artifacts he collected have been processed, and a report is being prepared which will describe the burial and its context more fully. However, preliminary information indicates that the shelter contains mostly Archaic and NeoIndian cultural remains and was inhabited between 1500 B.C. and 1400 A.D.

The skeletal parts were badly disturbed by burrowing animals, with most of the bones badly fragmented, but nearly all major bones are present. From initial impressions, the individual appears to be an adult male.

Teeth present include from the mandible: incisors (4), right canine (1), right premolars (2), and right molars (3); from the maxilla: a central incisor (1), lateral incisors (2), left canine (1), premolars (2), and both first molars (2), for a total of 18 teeth. Notches occur on the mandibular central incisors and right lateral incisor (Fig. 7). The left central incisor has the most pronounced notch, which is V-shaped and extends from the labial margin of the occlusal surface lingually four-fifths of the diameter of the crown; the notch is deepest on the labial aspect from where it tapers lingually. The alteration on each of the other 2 mandibular incisors consists of little more than a slight groove in the middle of the labial half of the occlusal surface.Similarly, a slight indentation occurs on the left labial edge of the occlusal surface of what may be a left lateral maxillary incisor.

All of the teeth display extensive crown reduction due to attrition. In particular the mandibular teeth displaying the grooves have no crowns remaining whatsoever, which is not uncommon in middle-aged adult Indians from the region. The grooves occur in the secondary dentine and root stumps. Another sort of alteration occurs on

Fig. 6.—Close-up of the notched teeth of the Taylor Ranch Burial. Note that only 1 set of notches can match when held in a single position and that the maxillary notches are wider than those of the mandible.

the right first maxillary molar, which has an interproximal groove on the buccal-distal corner at the junction of the crown and root.

As in the case of the Taylor Ranch specimen, the mandible and teeth of the Gun Sight Shelter specimen were shipped to the second author and subsequently returned to the Panhandle-Plains Historical Museum.

Discussion

As mentioned before, there have been less than a dozen mutilated or possibly mutilated teeth reported from North America. These teeth come from archeological contexts suggesting late time periods and areas of considerable Mesoamerican influence—late Puebloan from Arizona and Mississippian from Illinois and Georgia. The tooth modifications reported fall into 2 categories: namely, labial grooves and occlusal notches. Putting aside the question of the labial grooves and their possibly hypoplastic origins, the notched teeth can be divided into those with single notching and those with multiple. The Texas examples, of course, fall in the former category and are most similar to those from the Sikyatki Site in Arizona, which, perhaps signif-

Fig. 7.—Gun Sight Shelter mandibular fragment with 3 notched teeth: namely, right lateral and both central incisors. The mandible has been oriented to emphasize the notches.

icantly, is the geographically closest of the sites with reported mutilations.

There are essentially 2 methods by which the notched teeth from the Texas Panhandle could have been produced. One way is by purposeful filing presumably to alter the tooth form in a culturally prescribed manner. The other way is by accident. In this latter process, the teeth may have been used as tools, perhaps as a vise, to modify other objects that in turn altered the teeth themselves.

The notched teeth from the Texas Panhandle appear to result from intentional mutilation rather than the use of teeth as tools. In the case of the Taylor Ranch Burial, the sharp, clear-cut borders of the notches as well as the lack of juxtaposition between the mandibular and maxillary notches argue for mutilation. Although the Gun Sight Shelter notches are rounded and more groove-like than those of the Taylor Ranch Burial, these modifications can be explained by marked attrition. The notches probably represent the most apical aspect of what was formerly a much larger notch before attrition destroyed the crown.

Like the notched teeth from the Sikyatki Site, the Texas examples are much less elaborate than most examples reported by Romero (1970) from Mexico or even the few reported examples from the eastern U. S. Some of the other U. S. examples involve mutiple notches accompanied by labial grooves. Of course, the Texas examples once may have been more elaborate, before attrition destroyed most of the crowns.

The Texas examples appear to expand both the documented geographical and temporal ranges of notching in the United States. The geographical occurrence is somewhat surprising, since the Texas Panhandle lacks other evidence of significant direct Mesoamerican contact, although Southwestern influences may be present. The temporal extension is even more surprising, since all other examples of notching in the United States occur relatively late. The eastern examples are all from Mississippian sites, dating no earlier than A.D. 700 and probably much later. The Arizona specimen dates very late, possibly into the historic period. As stated earlier, the Texas examples may be considerably earlier, possibly even Archaic. This new evidence suggests that the practice of notching in prehistoric North America may have had a considerably greater geographical and temporal range than previously suspected.

Acknowledgements

We wish to thank Billy R. Harrison, Jack T. Hughes, and Billy Ray Thompson for making their unpublished data available; Jack T. Hughes and David Hughes for the field photographs of the Taylor Ranch Burial; Waldo R. Wedel and T. D. Stewart for encouraging our efforts; Stella Willey for the map and paste-up work; and Becky Tarwater for typing one of the manuscript drafts.

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ANNOUNCEMENT

WASHINGTON OPERATIONS RESEARCH COUNCIL

Wednesday, Jan. 19, 1977 "Planning and Evaluation in the Consumer Product Safety Commission." Joann Langston, Consumer Product Safety Comm.

Wednesday, Feb. 9, 1977 "Social Science Directions in the Current Administration." Arthur Spindler.

Wednesday, March 9, 1977 "Analysis of the Paperwork Flow in the Government." Warren Buhler, Staff Director, President's Commission to Reduce the Flow of Paperwork.

April 18–19, 1977 Annual Symposium. "Natural Resources Policy."

Wednesday, May 11, 1977 Annual Banquet.

All meetings will be held at the Center for Naval Analyses, 7th floor auditorium, 1401 Wilson Blvd., Arlington (Rosslyn) at 8:00 p.m.

BOARD OF MANAGERS MEETING NOTES

February 25, 1976

The 630th Meeting was called to order at 8:10 p.m. by President Abraham in the Conference Room of the Lee Building at FASEB. He introduced the officers for 1975–76: Dr. Florence H. Forziati, President-elect; Dr. Alfred Weissler, Secretary; and Dr. Richard H. Foote, Treasurer.

Treasurer.—Dr. Foote presented the Treasurer's report for 1975, which showed that income was about $6000 greater than expenditures. Although the investment income was lower than in 1974, the value of capital assets at year-end was $59,934.15, a substantial increase from $43,810.85 in 1974. The 1975 report was accepted on a motion by Dr. Robbins, seconded by Dr. Weissler. Treasurer Foote also presented the proposed budget for 1976, which estimates income at $34,319 and expenditures at $33,815. The budget was approved unanimously, on a motion by Dr. Morris, seconded by Dr. Rowen.

Investments.—The possibility of increasing the Academy's investment income was discussed in a presentation by Mr. George Mitchell of the Washington office of Moseley, Hallgarten and Estabrook, Inc. Mr. Mitchell noted that our current return is less than 4% on our investments in stock mutual funds; this could be more than doubled by switching into a capital bond fund. After a general discussion on the need for balancing current income against capital appreciation prospects, President Abraham appointed an *ad hoc* Committee, with Dr. Foote as chairman, to consider the matter further.

Divisional Structure.—President Abraham pointed out the need to activate the new divisional structure of the Academy by having the appropriate society delegates meet to elect a chairman for each Division. In order to accomplish this, he appointed the following temporary chairmen: Dr. James F. Goff for Physical Sciences and Mathematics, Dr. Mary Louise Robbins for Life Sciences, and Grover C. Sherlin for Engineering.

Journal.—Dr. Foote reported that it has finally become unavoidable to levy a page charge of $25, which is modest as compared with other journals. Symposium IV will be published as the March 1976 issue of the Journal.

Policy Planning.—Dr. Alphonse Forziati presented a written committee report, and discussed one of the items relating to a change of the Academy's name to "Washington Academy of Sciences and Engineering." The Board expressed favorable sentiment towards such a change, by a straw vote of 9 to 4. The Bylaws committee will be asked to prepare the necessary amendments to charter and Bylaws, which will then be submitted to the Academy membership for a vote.

Meetings.—Dr. Goff reported that the average attendance at the montly meetings this year has been 64. He attributed this success to the selection of a good variety of topics.

Public Information. Dr. Rowen expressed the hope that the new Divisions will help in publicizing the meetings and other activities of the Academy. He also reported on recent discussions of the societal interactions with science and engineering, which were held by the Science, Engineering, and Society Committee.

Grants-in-Aid. An announcement was made of the availability of approximately $639 to aid student projects in mathematics and science. It was also noted that the JBSEE is preparing a new list of ideas for student science projects.

Membership. Dr. Florence Forziati presented 4 nominees for fellowship: Dr. S. H. Durrani, Dr. Lloyd Knutson, Dr. K. G. Powers, and Dr. Rogert H. Lawson. All 4, plus Dr. William K. Blake who is the new delegate of the D. C. Chapter of the Acoustical Society of America, were unanimously approved as Fellows.

Scientific Achievement.—Dr. Kelso B. Morris thanked Ms. Ostaggi and the panel chairpersons for their labors in selecting the 1975 Scientific Achievement Award winners: Biological Sciences, Wayne A. Hendrickson, NRL; Engineering Sciences, Gerard V. Trunk, NRL; Behavioral Sciences, Julius E. Uhlaner, US Army Res. Inst.; Mathematics, Charles R. Johnson, Univ. of Md.; Physical Sciences, William K. Rose; Teaching of Science, Peggy Dixon, Montgomery College; Lamberton Award for Teaching of High School Science, Edythe G. Durie. The report was approved on a motion by Dr. Alphonse Forziati, seconded by Dr. Robbins. (See JWAS, Vol. 66, No. 2, pp. 152–156.—*Ed.*)

Tellers.—Mr. Buras reported the results of the recent election for 1976–77 officers, as follows: Richard H. Foote, President-elect; Nelson W. Rupp, Secretary; Mary H. Aldridge, Treasurer; Rita R. Colwell and Grover C. Sherlin, Managers-at-Large.

In addition, the change in bylaws and the affiliation of the Washington Paint Technical Group were approved by a large majority. Mr. Buras recommended that future ballots use a simple plurality system, and also only one side of the paper because some members fail to turn it over. The report was approved unanimously, upon a motion by Dr. Franz, and seconded by Dr. Robbins.

New Business.—Photographs of past presidents of the Academy should be preserved for the future, Dr. Robbins suggested. It was decided at least to maintain a file of such photographs, with consideration later on a public display.

Dr. Wagner advocated a greater exchange of meeting notices among the Academy's affiliated societies.

Dr. Argauer noted that the Insecticide Society of Washington had recently held its 300th meeting, and suggested that brief historical accounts of the affiliated societies are suitable for publication in the Journal of the Academy.

The meeting was adjourned at 10:35 p.m.—Alfred Weissler, *Secretary*.

NEW FELLOWS

Paul G. Campbell, National Bureau of Standards, Sup. Res. Chemist, in recognition of his contributions to organic chemistry and in particular to his publications on the photo-oxidation of asphalt and organic coatings. *Sponsors*: Florence H. Forziati, Alphonse F. Forziati.

Shung-Chang Jong, Head, Mycology Dept., American Type Culture Collection, Rockville, Md., in recognition of his outstanding work in mycology. *Sponsors*: Rita R. Colwell, Richard H. Foote.

Robert B. Leachman, Special Assistant, Nuclear Regulatory Commission, Wash., D. C., in recognition of his contribution to physics, and in particular his researches in nuclear fission and heavy-ion physics, and on safegards against misuse of nuclear materials. *Sponsors:* George Abraham, Florence H. Forziati.

Howard Lessoff, Branch Head, Naval Res. Lab., in recognition of his activities in solid state materials including magnetic memory materials, basic spin wave spectra interpretation and fundamental understanding of electronic materials. *Sponsors:* George Abraham, Emanuel Brancato.

Cyril Ponnamperuma, Professor of Chemistry; Director, Lab. of Chemical Evolution, Univ. of Md., in recognition of his extensive research on the chemistry of the origins of life. *Sponsors*: James F. Goff, Bradley F. Bennett.

Harrell Leroy Strimple, Curator & Research Investigator, Geology Dept., Univ. of Iowa, in recognition of his contributions to invertebrate paleontology, chiefly the Crinoidea. *Sponsors:* Florence H. Forziati, Alphonse F. Forziati.

John D. Walker, Microbial Ecologist, Environmental Technology Ctr., Baltimore, Md., in recognition of his outstanding scientific work in microbial ecology. *Sponsors:* R. R. Colwell, Richard H. Foote.

Marvin H. White, Advisory Engineer, Westinghouse Electric Corp., Baltimore, Md., in recognition of pioneering contributions to the theory and experimental development of charge coupled electron devices and imaging sensors. *Sponsors:* Arthur S. Jensen, George Abraham.

Sanford C. Adler, President, Management Factors Organization, McLean, VA., in recognition of his contribution to operations research, and in particular the application of governmental resources in the solution of problems relating to health and safety. *Sponsors:* Jean K. Boek, Joan R. Rosenblatt.

George E. Deal, NBS Operations Research analyst, in recognition of his contributions to the field of operations research and of his research, leadership, practice, and teaching in the area of management. *Sponsors:* John W. Rowen, James E. Fearn, Grover C. Sherlin.

SCIENTISTS IN THE NEWS

Contributions in this section of your Journal are earnestly solicited. They should be typed double-spaced and sent to the Editor three months preceeding the issue for which they are intended.

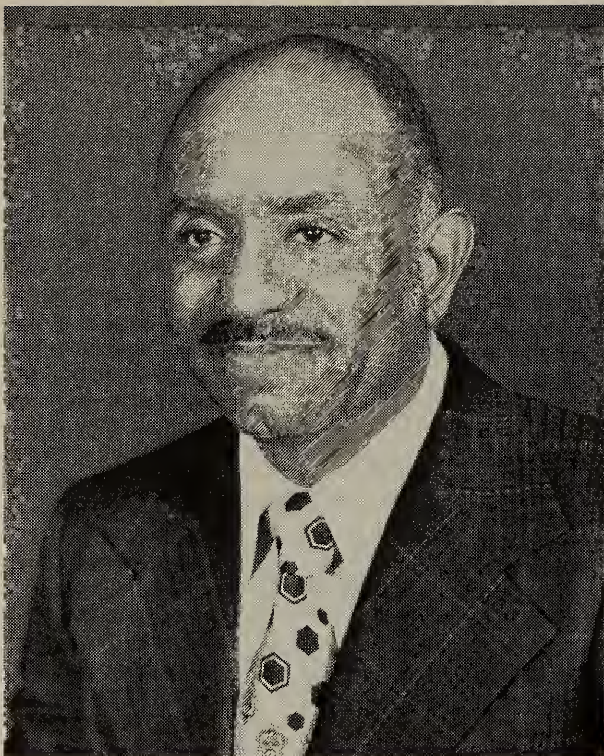
NATIONAL BUREAU OF STANDARDS

J. J. Diamond, Chief, Law Enforcement Standards Laboratory, NBS, has received the Department of Commerce Silver Medal Award for valuable contributions to the Nation's law enforcement officials by developing law enforcement equipment standards. He is a 1937 graduate of Brooklyn College, Brooklyn, NY.

DEPARTMENT OF THE ARMY

Howard S. Jones, Jr. has been given a Meritorious Civilian Service Award for his productive microwave antenna research. This second highest civilian award was presented to him for his important technical accomplishments and major improvements in a variety of Army weapon antennas for radar related systems.

Dr. Jones is the Chief of the Microwave Branch 150, at the US Army Harry Diamond Laboratories (HDL) Adelphi, MD. He is recognized nationally and internationally as an expert in the microwave field specializing in microwave devices and antenna arrays. His educational background includes B.S. and D. Sc. degrees from Va. Union University, Richmond, VA, certificate in



Howard S. Jones, Jr.

Engineering, Howard University, M.S.E.E. Buchnell University, Lewisburg, PA, plus other graduate work in Math, Physics and Engineering. He also completed the residential Executive Education program at the Federal Executive Institute, Charlottesville, VA.

In 1972 he was the recipient of the Secretary of the Army's Research and Study Fellowship award, and the inventor of the year (HDL) award, cited for his numerous contributions that have advanced the antenna state-of-the-art while providing solutions to critical antenna problem areas of modern weapon systems. He has also received several other awards and citations during his career, among which is included the Army Research and Development Achievement Award in 1975.

Early this year Dr. Jones was named to the Thirty-Ninth Edition of Who's Who in America for his microwave contributions that have bettered contemporary society.

He has served as a technical Consultant to government agencies and private industry, and was an assistant professor at Howard University's School of Engineering for several years. Other accomplishments include more than 30 technical reports, numerous oral presentations and publications in the Scientific Literature. He has received 24 US patents relating to microwave antennas, devices and design techniques.

Dr. Jones holds FELLOW status in the Institute of Electrical and Electronic Engineers (IEEE), American Association for the Advancement of Science (AAAS), and the Washington Academy of Sciences (WAS). He is a member of the Antenna and Propagation Society, the Microwave Theory and Techniques Society, and a registered professional engineer in the District of Columbia.

IEEE

F. L. Hermach of the Electricity Division has received the 1976 Morris E. Leeds Awards of the IEEE for outstanding contributions to the field of electrical measurements. The award, consisting of a certificate and $1,000., was presented on June 28, 1976 at the Conference on Precision Electromagnetic Measurements in Boulder, Colorado.

The award, one of the most prestigious in its field, was given in recognition of Mr. Hermach's research and development of extremely accurate ac-dc transfer standards and for his outstanding services on standards committees. All ac voltage and current measurements depend on these transfer standards or comparators, which relate the ac quantity to the basic dc standards at NBS. In his 37 years at the Bureau Mr. Hermach has developed and verified new forms of comparators, with greatly increased accuracy and range. He has also represented NBS on major standards-writing committees on electrical measurements and on hazards from electricity.

SOCIETY OF COSMETIC CHEMISTS

Alfred Weissler of Chevy Chase, Md. has been installed as president of the Mid-Atlantic chapter of the Society of Cosmetic Chemists for 1977. He has served previously as president of the Chemical Society of Washington and president of the Washington chapter of the Acoustical Society of America.

NAVAL RESEARCH LABORATORY

Jerome Karle, Chief Scientist of the Laboratory for Structure of Matter at the Naval Research Laboratory (NRL) here, has been elected a member of the National Academy of Sciences (NAS) and also was named recipient of the 1976 Captain Dexter Conrad Award for Scientific Achievement . . . both within one week.

Dr. Karle is the fourth NRL member to be elected to the NAS, considered one of the highest honors that can be accorded to an American scientist or engineer. The other NRL members are: Drs. Herbert Friedman, Richard Tousey, and Samuel Collins.

NAS elected Dr. Karle and 74 other new members to the society last month in recognition of their distinguished and continuing achievements in original research. Their names were announced at the business session of the 133rd annual meeting of NAS April 27.

The Academy, a private organization established in 1863 by a Congressional Act of Incorporation signed by President Lincoln, serves as official advisor to the federal government, upon request, in any matter of science or technology.

The Captain Robert Dexter Conrad Award for Scientific Achievement is considered the highest recognition the Department of the Navy can bestow on any of its scientists engaged in research and development for the Department.

The Chief of Naval Research, Rear Admiral R. K. Geiger, in a letter to Dr. Karle concerning the award, said "Your distinguished contributions in the study of the structure of matter in vapor, crystalline and amorphous states fully merit this recognition. Your pioneering efforts have advanced the scientific prestige of the Navy and the Nation."

Dr. Karle received the Navy's Distinguished Civilian Service Award, the highest Navy award available to civilian employees, in 1968 for his "pioneering advances, both theoretical and experimental, and for his leadership in the fields of the structure analysis of matter by electron, x-ray, and neutron diffraction." His work made it possible to study the structures of a large variety of materials of interest to the Navy.

Dr. Jerome Karle

For the past 34 years, including almost 32 at NRL, Dr. Karle has conducted theoretical and experimental research in electron diffraction, x-ray diffraction, and neutron diffraction as they pertain to structural analysis of matter. With these three distinct but related methods, scientists delve into the infinitesimal world of molecules and crystals in search of interatomic distances and atomic arrangements. This knowledge contributes to fundamental progress in science in such fields as organic and biological chemistry, geology,and solid state physics.

An occasional collaborator in Dr. Karle's work is his wife, Dr. Isabella Karle, also a noted scientist, recently honored with the Garvan Medal of the American Chemical Society and an honorary Doctor of Science degree from the University of Michigan. They have collaborated on identifying the chemical nature and solving the three-dimensional structures of a number of highly active substances of interest to physiology and medicine.

A native of New York City, Dr. Karle holds degrees from City College of New York (BS—1937), Harvard University (MA—1938), and the University of Michigan (MS and PhD—1944). Before joining the NRL staff in 1944, he had been associated with the Manhattan Project and had done contract work for NRL at the University of Michigan, where he also taught.

In 1968, Dr. Karle was named to the Chair of Science for the Structure of Matter at NRL, which was created in recognition of his distinguished scientific service. In 1970 he and his wife shared the Hillebrand Award of the Chemical Society of Washington.

Dr. Karle has authored or coauthored over 150 manuscripts for technical journals. He is a Fellow of the American Physical Society and the Washington Academy of Sciences. His membership in professional societies includes the American Mathematical Society, American Chemical Society, American Association for the Advancement of Science, American Crystallographic Association, and the Philosophical Society of Washington. He is a past-president of the American Crystallographic Association and is currently a consultant to the National Science Foundation. He is also a member of the American Heritage Society and the National Society of Literature and the Arts.

The Karles live in Falls Church, VA. They have three daughters, Madeleine, Jean, and Louise. Madeleine is a geology major at Virginia Polytechnic Institute and State University, and Jean, Louise and Louise's husband, Jonathan Hanson, all have earned PhD degrees in chemistry.

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Type manuscripts on white bond paper either 8½ by 11 or 8 by 10½ inches. Double space all lines, including those in abstracts, tables, legends, quoted matter, acknowledgments, and references cited. Number pages consecutively. Place your name and complete address in the upper right hand corner of the title page.

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Include tables only when the same information cannot be presented economically in the text, or when a table presents the data in a more meaningful way. Consider preparing extremely complicated tabular matter in a form suitable for direct reproduction as an illustration. In such cases, the use of the typewriter is not recommended.

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The Journal

This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

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Anthropological Society of Washington	Jean K. Boek
Biological Society of Washington	Inactive
Chemical Society of Washington	Mary H. Aldridge
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American Institute of Aeronautics and Astronautics	Franklin Ross
American Meteorological Society	A. James Wagner
Insecticide Society of Washington	Robert J. Argauer
Acoustical Society of America	Delegate not appointed
American Nuclear Society	Dick Duffey
Institute of Food Technologists	William Sulzbacher
American Ceramic Society	Inactive
Electrochemical Society	Delegate not appointed
Washington History of Science Club	Inactive
American Association of Physics Teachers	Bernard B. Watson
Optical Society of America	Ronald W. Waynant
American Society of Plant Physiologists	Walter Shropshire
Washington Operations Research Council	John G. Honig
Instrument Society of America	Inactive
American Institute of Mining, Metallurgical and Petroleum Engineers	Carl H. Cotterill
National Capitol Astronomers	Benson J. Simon
Mathematical Association of America	Patrick Hayes
D.C. Institute of Chemists	Miloslav Recheigl, Jr.
D.C. Psychological Association	John O'Hare
The Washington Paint Technical Group	Paul G. Campbell
American Phytopathological Society	To be appointed
Society for General Systems Research	Ronald W. Manderscheid
Human Factors Society	To be appointed

Delegates continue in office until new selections are made by the representative societies.

ANNOUNCEMENT

BELTSVILLE SYMPOSIUM II: BIOSYSTEMATICS IN AGRICULTURE
BELTSVILLE AGRICULTURAL RESEARCH CENTER
BELTSVILLE, MARYLAND
MAY 9–11, 1977

In 5 symposium sessions leading investigators will lecture or engage in panel discussions on the role that biosystematics has in agriculture. Main topics will include new techniques, taxonomic theories, uses of taxonomic and biosystematic data, especially predictive applications, and the planning and direction of biosystematic research. In addition, a poster session and mixer is scheduled for the evening of May 9. Manned displays at the mixer should generate valuable discussion.

For further information, send lower portion of this notice to:

Dr. James A. Duke
Publicity Committee, BARC Symposium II
Plant Taxonomy Laboratory
Room 117, Bldg. 001, BARC West, USDA
Beltsville, Maryland 20705 U.S.A.

BELTSVILLE SYMPOSIUM II: BIOSYSTEMATICS
IN AGRICULTURE

Please send further information on the Symposium to:

NAME ______________________________

ADDRESS ______________________________

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The Scientific Basis for Timber Harvesting Practices[1]

David M. Smith

Professor of Silviculture, Yale University School of Forestry and Environmental Studies, New Haven, Connecticut 06511

ABSTRACT

Silviculture, the applied ecology of forestry, is fundamentally a planned simulation of the seemingly destructive disturbances, small or large, gentle or severe, which have in nature created kinds of forest vegetation now regarded as desirable for human needs.

Silviculture is the part of forestry that is the applied science of growing stands of trees. Trees have to live outdoors through winter and summer, during dry years and wet, usually on poor land unsuitable for agriculture; society also prices wood and other benefits at a low rate; therefore, it has always been necessary for foresters to work very closely with rather than against natural processes. As a result, silviculture became a form of applied ecology even before the word was coined by a German scientist during the last century.

The basic objective of silviculture, in any given place, is to create a certain desirable kind of vegetational development. The fundamental analytical procedure is to determine the processes that created this in nature and then to simulate them directly or indirectly. The astonishingly paradoxical point of all this is that the ultimately constructive guiding force in replacing old with new or even with steering the development of established vegetation is lethally destructive disturbance.

It was said long ago and probably in a language other than English that the forest is built with the wise use of the axe, the same tool with which it can be witlessly destroyed. This remains at least figuratively true even though the number of lethal constructive weapons has increased. Fire (Fig. 1) and grazing animals probably came before the stone axe in human manipulation of forest vegetation.

Let me attempt to indicate to you why the silvicultural guidance of the establishment and growth of forests has to depend on the judicious killing of trees and other components of the vegetation. The killing may be of single individuals or of both large and small patches thereof. In a certain, somewhat academic sense, the question of whether the killing is or is not done by harvesting trees for useful products is rather incidental. The fact that this mode of tree killing can pay the costs and yield a profit is immensely advantageous; however, the wise long-term management of a picnic grove would necessitate killing some trees. We might well do it whether anyone ever used

[1] Presented at a joint meeting of the Washington Academy of Sciences and the Washington Section, Society of American Foresters, Arlington, Va. November 18, 1976.

wood or not. If we can sell the wood, the net cost can be very substantially reduced.

Tree killing is the main silvicultural tool because forest vegetation typically fills all of the available growing space and cannot be changed or guided in its development without creating vacancies. Vegetation in general, and that of woody perennials in particular, hungrily expands its foliar cover and roots to fill all of the physiologically inhabitable space above and below ground. The occupancy soon becomes so complete that nothing new can be added unless some growing space is made vacant by killing something. In a more subtle way, the growth of one established plant can be enhanced by killing a competing neighbor. This kind of partial disturbance would merely speed natural development if the favored plant would have ultimately overgrown and shaded out the one that's artificially killed; however, if nature would have caused an opposite outcome, the partial disturbance could somewhat alter the course of development.

Any kind of vegetation tends to fill the growing space. With forests, it is simply more complete and more obvious. The phenomenon of the perennial woody stem is the most efficient terrestrial device for arranging energy-gathering foliage such that it is dispersed in depth in a transparent medium. Suspensions of floating algae waste little or nothing on supportive stems, but the medium is less translucent and there is no vertical conductive mechanism to take care of moving chemical nutrients upward. Water supply is something of a problem on land. In fact, forests with a closed foliar canopy exist only where there is plenty of water. Where water is in short supply but still sufficient for some trees to exist, their root systems often fill the whole soil stratum but the water that they pick up is sufficient to support only an incomplete foliar canopy.

I should underscore the point that the trees grow to fill the *available* growing space but not to use up all the growth-supporting factors. If they used all the growth factors, there would be no water left for stream flow; everything but the green light would be used and things beneath the forest would all look green. Absolute shortages of a given essential factor or seasonal shortages limit the capacity to use others. A phosphorus shortage might limit the amount of leafy photosynthetic apparatus and thus the amount of leaf tissue to transpire water; this would in turn release more water to stream flow. One manifestation of seasonal shortages with temporary surpluses is the development of understory vegetation with short annual cycles of active growth.

The beautiful spring flora of the eastern deciduous or hardwood forest is one of the classic manifestations of this; the spring flowers can burgeon to take advantage of heat, light, and water faster than the trees can. One might speculate that the microclimate near the ground beneath the cover of tree stems was less subject to frost than unshaded shoots at the top of the crown canopy. In any event, there is obviously a temporarily productive and reasonably secure niche at the forest floor in which the handsome plants can quickly grow and flower.

In silvicultural practice, we distinguish between two different kinds of lethal disturbance. Those intended to replace old stands with new ones are called regeneration cuttings; most of the rest of this talk will be about them. These cuttings have to be comparatively large in areal extent or at least large enough that new seedlings or small, young trees rather than old, adjacent ones fill the vacated growing space.

The other kinds of disturbance, traditionally called "intermediate cutting", are those in which scattered individual trees or, at most, offending vertical strata of trees, are removed or eliminated to favor other existing trees. Since cutting is not always involved, especially with modern development of tree-killing chemicals and more purposeful use of fire, the term "tending" is probably more appropriate. Anyhow, tending operations are aimed at guiding or accelerat-

Fig. 1.—Typical surface fire burning the grassy forest floor beneath a western ponderosa pine forest. This common natural phenomenon will kill some of the trees and pine seedlings will colonize the resulting vacancies. (U. S. Forest Service photo.)

ing development of established vegetation rather than its replacement. Such cuttings, "intermediate" in time between the regeneration cuttings, are almost always in the nature of partial removals.

Stands of forest trees can live so long and be so infrequently subjected to disturbance that it is hard to convince anyone that they are ever disturbed at all. Many forests owe their present characteristics to rare events which are not necessarily always destructive. The forst fire or windstorm of an hour's duration once every two or three centuries can govern the vegetational developments of the intervening time. In fact, it is either such events or attacks by fungal or insect pests which have been the initiating events of just about all of our natural forests. Most of the exceptions simply involve some less common kind of lethal disturbance such as landslides or volcanic eruptions.

The natural vegetation of any locality is a kind of repertory of species collectively adapted to fill virtually any kind of vacancy or new ecological niche that has come into existence as a result of natural disturbances (Fig. 2). There are plants that can claim the minimal growing space afforded by a rotten knot hole high up on a tree as well as lichens, algae, and mosses that colonize the surfaces of rocks and tree bark. Part of the solution to silvicultural regeneration problems is determining the kind of vacancy that favors the desired species (plural or singular) more than unwanted competitors.

It is not enough that they be able to get established; sooner or later, the desirable trees must be in an environment in which they can grow faster in height than the undesirable. Although one can strive to create the right conditions at the time new forest vegetation is established, some sort of corrective action is often necessary later on.

Some species are adapted to colonize severely exposed areas, especially those created by hot forest fires (Fig. 3). These species, aptly termed pioneers, can endure wide extremes of temperature and grow fast enough to push their roots

Fig. 2.—Newly germinated conifer seedling; survival at this stage depends on microclimatic factors which can be deliberately predetermined by cutting patterns. (U. S. Forest Service photo.)

quickly below the surface inch or two that is subject to severe desiccation. They must grow fast if they are to survive and require lots of light to support their rapid growth and high respiration rates. Among the natural fire-following species that fall in this category are jack and lodgepole pines as well as the aspen poplars and certain birches. In silvicultural practice, the regeneration of such species usually requires the complete removal of the old forest in clearcutting; however, certain other effects of the fires have to be simulated as well.

In a certain sense, fires kill forests from the bottom up because the heat is generated mainly by the burning of the litter of the forest floor. Some mineral soil may have to be exposed through such litter destruction if the seeds of the pioneers, which are often small and wind-dispersed, are to have satisfactory contact with the stable moisture supply of firm soil. It can also be very important to get the effect of killing of the subordinate vegetation which often includes tree species that started under the old stand but are not necessarily desirable or well-adapted to the soil conditions.

At the other extreme are the so-called shade-tolerant species that not only endure shade but also tend to require it in the early stages of development. These species have characteristics such as low respiration rates, high chlorophyll content, and efficient leaf arrangement that enable them to stay alive at low light intensity. Their seedlings do not grow rapidly in height simply because there has never been any survival value in doing so just as they have also sacrificed much ability to endure exposure.

These species include certain spruces, most true firs, hemlocks, and most maples and oaks. They are generally adapted to persist for many years beneath old stands of trees but to retain the capacity for initiating rapid height growth when released by lethal disturbances that kill forests from the top downward. The natural disturbances to which they are adapted are windstorms (Fig. 4), the lethal effects of defoliating insects, and fungi or other pests that weaken tree stems enough to cause them to break. Once these so-called ''advance growth'' species are established as seedlings or small saplings, it is possible to release them in any pattern of space and time that is appropriate for other management purposes; however, their regeneration fails if major removal cuttings take place

Fig. 3.—Very hot crown fire in western conifer stand. A new natural stand dominated by pioneer tree species would follow this severe disturbance. Clearcutting simulates this kind of disturbance but without certain baneful effects of such highly dangerous fires. (U. S. Forest Service photo.)

FIG. 4.—Severe blowdown in a west coast forest. If there is no subsequent fire (which would be very hot), the new forest will develop from advance growth already present or from progeny of the scattered remaining trees. (U. S. Forest Service photo.)

before the seedlings are adequately established.

As is usually the case in such matters, there are lots of species that represent adaptations to microenvironment that are intermediate between the extremes just described. Actually, there is a gradational series of adaptations from one end to the other. Many of our most important species fall into this broad intermediate category. They may individually have some special ecological requirements that must be met but they are generally flexible enough that a variety of regeneration cutting patterns and silvicultural techniques can be applied. Among the species in this group are Douglas-fir and such important pines as loblolly, slash, ponderosa, red, and the five-needled whites. In nature, most such species regenerated after fires that killed many trees but not all of them; however, it is not wise to generalize much about this point because windstorms and other kinds of disturbance were also commonly involved.

Much of what I have just said relates to the applied ecology of securing regeneration from seeds applied naturally or artificially out in the forest. While the silvicultural techniques that closely simulate nature often work and have such advantages as low out-of-pocket cost, it would be wrong to leave the impression that they always work or work well when they do. The numbers of seedlings are often either too many or too few, sometimes within the same acre. Furthermore, most trees do not bear seeds every year, nor does the rain always fall at the right time after the seeds fall.

The planting of nursery-grown seedlings is a way of by-passing many of these problems of timing and stand density. It is also coming to be increasingly prominent as a means of establishing stands of the progeny of selected trees.

There are considerations in addition to the ecological adaptations of young trees that govern the cutting patterns chosen to replace forests. All things have to be conducted in the context of economics, both that of the human needs of the next century and the frantic concerns of the present. The society of the day is concerned about its posterity but seldom to the extent of investing lavishly in it. A dollar spent on regeneration now is often required to hold promise of a return of $46.90 at 8% compound interest 50 years hence. Since society seems to expect wood to be cheap, harvesting costs are continually scrutinized and usually trimmed to the lowest level that law and prudence will allow.

Logging costs tend to weigh in favor of clearcutting in large units of area where the timber is large and on rugged terrain (Fig. 5). This is because ponderous machinery and expensive roads are required. The costs of roads and of moving in machinery are fixed costs and it is desirable to spread them over as much harvested product as possible.

If the terrain is easy and the trees smaller, the fixed costs are less significant, so more attention is paid to the variable costs. These are basically those of handling trees one by one and are inversely related to tree size. If it costs more to harvest a unit of produce from small trees than large, loggers would, if left to their own devices, cut only the larger ones.

It would be a remarkable coincidence if the short-term economic logic involved in minimizing the costs of one logging operation also optimized the long-term net benefit sought in managing a stand of trees through one rotation from birth to replacement. Some sort of compromise must be sought not only between long- and short-term financial considerations, but also among all the objectives and limiting factors involved in forest management.

One of the key decisions in forest management and silviculture involves the question of which parts of a whole forest should be composed of even-aged stands and which, if any, of uneven-aged stands. There are many factors which weigh in favor of having stands even-aged, or perhaps more precisely, more nearly even-aged than otherwise. The reasons why foresters the world over keep coming back to policies of even-aged manage-

Fig. 5.—Clearcut patches in Pacific Coast Douglas-fir; the nursery-grown seedlings that have been planted after the slash burning are too small to be visible. (Photo by author.)

ment are many and variable, although not of universal validity.

Before proceeding further, it is perhaps well to point out that even-aged management does not require clearcutting. The technique called shelterwood cutting, in which a new stand is started under an old one, is a method of even-aged management which becomes prominent when good forests have been developed (Fig. 6).

Matters of economy in administration, harvesting, and silvicultural treatment are certainly factors which favor even-aged management. It does help and save money to be able to conduct one kind of operation at a time over areas some acres in extent. It becomes both confusing and costly if one is simultaneously doing all things appropriate to all stages of stand age within a patch-work of sub-stands of differing age.

The alternative policy of uneven-aged management often requires that the entire road network of a forest be almost equally and continuously used. With even-aged management, operations are more concentrated in space, so parts of the road system can be left out of use for long periods. This not only saves money but reduces the amount of erosion-prone road surface; this is very crucial because nearly all of the soil and water damage that can be charged against timber-production forestry comes from roads.

Another common reason for even-aged management is simply that most stands are even-aged already and are difficult to change. In nature, many stands arise from the kinds of catastrophic disturbance that create even-aged stands. The very heavy cuttings, with or without ill-controlled fires, that characterized logging done without conscious intent of future management, often left even-aged stands. In fact, there are large areas of the country where the liquidation of old forests proceeded so rapidly that most of the stands are of nearly the same age; this creates a situation very difficult for securing the distribution of age classes necessary for sustained yield. It is not possible to change an existing pattern of age-class distribution in forests without replacing some trees prematurely or holding some beyond maturity.

Fig. 6.—Shelterwood cutting in Pacific Coast Douglas-fir with seedlings about 8 years old that naturally established themselves in the new environment created by heavy, partial cutting. (Photo by author.)

True uneven-aged management, in which distinctly different age classes are maintained within a stand, is appropriate to somewhat less common circumstances. The simplest are where there are already at least two immature age classes and it would be wasteful to liquidate them prematurely. The other is where there is some reason to want to have fairly large trees on the ground at all times. This is logical in certain recreation or scenic areas and where there is risk of land-slides. This kind of management is also useful on small holdings on which the growing timber is handled as a kind of fluctuating bank account with limited silvicultural investment.

Uneven-aged management or the so-called selection system of silviculture (Fig. 7) is very difficult to apply if the goal is to make each small stand a perfect, self-contained, sustained-yield unit. The methods for regulating harvests under

Fig. 7.—An uneven-aged stand of mixed conifers created by a series of selection cuttings conducted over a 30-year period along a scenic highway in a national forest near Crater Lake, Oregon. (Photo by author.)

such management are both complicated and highly unreliable. The advocates of the selection system and of uneven-aged management often destroy their case by doctrinaire insistence on making stands into sustained-yield units. There is plenty of room for incomplete applications of the selection system, but it is better to employ them only where real reasons exist for doing so and not merely because of whim or naturalistic mystique.

Nature can create large even-aged stands and also those with several irregularly distributed age-classes; however, the theoretical all-aged stand with all age-classes equally represented would be just as much of an artificial creation as a 1,000-acre plantation of loblolly pine, and so much harder to create that none are known to exist.

In considering some aspects of recent American silvicultural practice, it is necessary to point out that it is all still very new as far as the long time-scale of forestry is concerned. The whole idea of growing trees consciously really did not take hold to any significant extent in this country until the time of World War II. Most forestry on industrial holdings started about then. Before that time, most public forests were regarded as economically inaccessible so they were protected, but little was harvested from them.

Part of the reason why there is so much clearcutting now is that foresters of today have inherited a large backlog of stands in need of replacement. Some of these are the rather degraded kinds of vegetation left over from decades or from centuries of reckless cutting and inadequate protection. Others may be tottery old-growth stands that do not stand up well under partial cutting and consist largely of over-mature trees. Stands of this kind must generally either be reserved as museum pieces or replaced by clearcutting. It is very probable that there are lots of sites on which clearcutting will be a one-time-only operation as a stage-setting device and that subsequent stands will be handled by some variant of the shelterwood method. This method provides plenty of ways of getting the advantages of partial cutting under even-aged management, but it is hard to apply unless one has already created a good, vigorous and accessible forest.

Clearcutting is also involved in the quasi-agricultural kinds of silviculture aimed at intensive timber production. If thorough-going treatments with machinery or fire precede planting and if no reliance is placed on natural seeding, then it is expedient to employ clearcutting and planting. At present, one of the chief reasons for doing this is the attempt to establish genetically superior forests. This approach is especially fashionable on industrial holdings. Previous experience makes it logical to anticipate that it will work well with some species and on some soils, but that it will fall victim to insects, fungi, wind and other damaging agencies elsewhere. In some instances, the high expense will prove richly rewarding but in others there will be disappointment. The important thing is that this technique cannot be embraced as a universal solution nor condemned out of hand as a violation of nature; however, it does work best on somewhat dry sites where fire has been common in nature and has also produced rather simple stands of fast-growing pioneers.

There is no one best way of treating all forests; they are simply too variable in their natural behavior and in the socioeconomic circumstances that affect their management. The forests of this country are not only vast in extent but they include just about every kind of forest that might be found outside the tropics and even some of those. Furthermore, the silviculture that was best for the forest of a paper company on one side of a fence would differ from that of a bank teller on the other side.

The best decisions about silviculture practice are made by experienced, observant foresters on the ground who have the capacity, responsibility and authority for the necessary analytical thought. Attempts to dictate silvicultural decisions from distant points are inevitably based on sweeping, simplistic generalizations. Even if the prescriptions from distant sources fit 80% of the cases well, some disastrous failures can result from the 20% that do not fit. It matters not whether the distant source of authority is a legislature, the headquarters of either a government bureau or a corporation, or some university ivory-tower.

It has recently become fashionable to decry the techniques of silvicultural practice as a kind of ecological desecration. This is almost as far from the truth as one can get. Even the most artificial kind of forest must be quite close to a state of nature; if it isn't, it does not endure anyhow. It is logical to be concerned about the erosion which roads and other soil disturbance can induce. Much of this can be prevented. Nevertheless, it is perhaps often overlooked that the worst forestry causes far less erosion than the best of clean-cultivation agriculture. All living resources are renewable and there appear to be none more infinitely renewable than those of the forest. Furthermore, of all of the structural substances used by our civilization, there is none which can be produced and used with less input of energy than wood. Provided that efforts to clean up pollution from wood-pulp mills continue, it can also be said that none give less output of pollutants.

This country has a lion's share of the world's productive forest land. It is no recommendation for our past performance that we are net importers of timber and will probably remain so into the next century even if we start even greater intensification of forestry now. The question of whether we can put American forestry into the same key role as American agriculture depends on what is done in managing the myriad of small ownerships. These include not only the majority of the forest area but also a very high proportion of the most productive and accessible land. The contribution from public and industrial forests can certainly help, especially in the near term, but it cannot be enough to carry all the burden.

Our best hope for indefinite economic survival may lie in nuclear power; our surest hope is in protecting *and using* the productive capacity of our field and forest soil.

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Washington Junior Academy of Sciences Christmas Convention, 1976

Elaine G. Shafrin, *et al.*

Washington Academy of Sciences Committee on Encouragement of Science Talent

Each year the WJAS sponsors a Christmas Convention at which high school students have the opportunity to present their research in a format similar to that of professional society meetings. A call for papers is issued to all public, private, and parochial high schools in the Greater Washington Metropolitan Area; participation is not limited to WJAS members. From the written theses received in response, a panel of adult scientists and educators selects a limited number for oral presentation by the student author in an auditorium before the Convention audience of WJAS members and interested adults. Provisions are made for a question period following each presentation. A second panel of judges then evaluates the presentations. Modest monetary awards (from $5.00 to $20.00) are presented for the highest ranked papers. Additionally, the student winning the first prize is sent to represent the WJAS at the National Meeting of the Association of Academies of Sciences, held in conjunction with the AAAS Meeting.

The 1976 Convention was held on Saturday, Dec. 18, at the NASA-Goddard Space Flight Center. The program was organized and chaired by Gary Neben, WJAS Vice-President and a senior at Herndon High School. The morning session was devoted to the student presentation of the eight papers for which the abstracts appear below. The papers were judged by a panel recruited by Dr. Russell W. Mebs, a Senior Advisor to the WJAS. In addition to Dr. Mebs (physicist, retired from NBS), the panel comprised Mr. Alfred Gunnersen, Jr. (mathematician, TRW), Dr. Peter H. Heinze (plant physiologist and biochemist, retired from USDA Agriculture Research Center), Dr. Jay Lee Mead (astronomer, NASA), and Mr. Joseph Pearlstein (technical writer, retired from the Harry Diamond Laboratories). Following a brown-bag lunch there was a tour of the NASA facility, conducted by Mr. Elva Bailey of the NASA staff. Highlights of the tour were the visit to the Master Control Room and Communications Center. The Convention then reconvened for the presentation of Certificates of Commendation to the student authors, the judges, and Mr. Bailey. After presentation of cash prizes to the authors of the four papers ranked highest by the judges for this year's Convention, the announcement was made that the winner of the 1975 Convention, Miss Allison Stark, would be attending the AAAS Meeting in Denver, Colorado in February, 1977. Appreciation was then expressed to Mrs. Dayna Smith, Senior Advisor to the WJAS, for her efforts in coordinating the meeting and to the TRW Company which had donated the money which made possible the granting of financial awards.

Abstracts of the papers are presented here. The first four projects won first, second, third, and fourth places in the order in which they appear.

THEOREM OF THE CARDINALITY OF INFINITE PERMUTATION SETS

Dwight Barkley

Crossland High School, Camp Springs, Md.

The theorem presented in this paper states that the cardinality of an infinite ordered set, S, is transcended by the cardinality of the permutation set (the set of all possible permutations) of S. The proof makes use of the indirect method by assuming that there exists a one-to-one correspondence between S and the permutation set of S. This is then reduced to a contradiction by finding a permutation of the elements in the set S that could not be in the range of any one-to-one mapping of S onto the permutation set of S. The proof of the theorem then follows immediately from the fact that S is a subset of the permutation set of S.

Throughout the proof of the theorem no inferences have been made as to the kind of infinite ordered sets involved. This permits this theorem to be applicable to any kind of infinite ordered set, numerical or abstract, and so other infinite sets may be constructed from pre-existing sets. Also, this theorem provides a direct way of comparing the cardinality of certain known sets. Thus the theorem developed in this paper provides the field of mathematics with another theorem, which adds to its ever growing structure.

ENZYME KINETICS—POSITIONAL EFFECT OF AN ORGANIC GROUP ON INHIBITIONS

Lawrence R. Weatherford

West Springfield High School, Springfield, Va.

Indole is known to be a competitive inhibitor of alpha-chymotrypsin. A project was undertaken on the hypothesis that each time methyl groups were attached to various positions on indole, a unique effect on inhibition of the enzyme would result. Kinetic rate constants were determined for 4 different methyl analogs. Using this data, an explanation of the observed effect in terms of a bonding analysis was determined.

Project results revealed that there are varied effects among the methyl analogs and that there are 3 prominent factors which determine the unique effect which the inhibitor has upon the enzyme.

THE DIFFERENTIAL EFFECT OF SILVER NITRATE SOLUTIONS ON *Herpes simplex* VIRUS

Kenneth Johnson

Sidwell Friends School, Washington, D. C.

The antiviral capabilities of varying silver nitrate ($AgNO_3$) solutions was tested on *Herpes simplex* virus types 1 and 2 in Vero cell cultures, using a plaque neutralization assay.

The stock virus suspensions were diluted to contain the desired number of plaque forming units. The virus titrations and dilutions of silver nitrate were carried out, using 10-fold dilutions. The 2 diluents used for silver nitrate were lactalbumin hydrolysate (LAH) and 12.5% ethyl alcohol. Equal volumes of silver nitrate and the diluted test virus were combined. LAH and ethyl alcohol controls were used as a test for tissue toxicity.

Falcon flasks containing Vero cells were inoculated with the test virus dilutions. The flasks were incubated for 1 hr at 37 C. After the incubation period, nutrient agar overlay was applied to the cell cultures. The flasks were then incubated for 5 days at 37 C. The test was stained on day 5 using a similar agar overlay containing neutral red. The flasks were incubated for 24 hr at 37 C; after the incubation period, all viral plaques were recorded.

The experiment verifies the fact that silver nitrate solutions effectively inactivate both strains of *Herpes* viruses. Silver nitrate solutions exhibit greater effectiveness against type 1 HSV than against type 2 HSV. Herpes type 1 shows greater sensitivity to both forms of silver nitrate solutions. Type 2 viral activity is greatly reduced in solutions of silver nitrate containing ethyl alcohol.

It is believed that ethyl alcohol aids in virus inactivation by eliminating the lipoprotein envelope surrounding the virion. The antiviral effects of silver nitrate may be due to the concentrations of silver ions held in the final solution. It is possible that the silver ions may bond to the lipoprotein envelope, altering the viral receptor sites. Since the virus can no longer attach itself effectively to the cell surface, it loses its potential for infectivity.

This experiment might prove useful as a simple, effective laboratory method to differentiate between *Herpes* type 1 and type 2 strains due to the 2 different rates of viral inactivation.

ANALYSIS OF DATA DESCRIBING GAMMA RADIATION PRODUCTION FROM POSITRONEUM DECAY IN VARIOUS SOLIDS

Bruce Reynolds

West Springfield High School, Springfield, Va.

When high-energy positrons interact with a metal or crystal, a stable atom called positroneum is formed. This atom consists of a positron and an electron circling each other. Eventually, the two particles will circle into each other (attracted by opposite charge), and annihilate. The 2 gamma rays that are created will be expelled at an angle of about 180°. The extra momentum carried by each particle in the positroneum, however, will be transferred to the gamma radiation, where it will manifest itself in the shrinking of the 180 degree angle to 179 or 178 degrees. By measuring this angle we can calculate the momentum distribution of the electrons in the positroneum. Because these electrons are selected randomly from the free electrons in the target, they are completely representative of these free electrons.

Analysis of this data is useful in a number of different areas: first, Fermi levels, knowledge of which is in demand now for studies of magnetism of alloys, can be calculated. Second, the free electron theory of metal can be verified. Third, positroneum can be used to study electron vacancies in semiconductors and crystal imperfections.

THE EFFECTS OF PHOSPHATE DETERGENTS ON THE RESPIRATORY AND EXCRETORY RATES OF *Carcinus maenas*

John Ross

Sidwell Friends School, Washington, D. C.

The effects of different concentrations of phosphates on the respiratory and excretory rates of the green crab, *Carcinus maenas*, were analyzed at mean summer temperatures. Household detergent was used because of its prevalence and its importance as a major form of phosphate pollution found today.

Results support the theory that phosphate detergents at high concentrations produce a greater strain on the metabolism of *C. maenas* than pure phosphates at the same concentration. At low concentrations pure phosphates have a greater effect on *C. maenas's* metabolism than the low concentration, low phosphate detergent.

WHAT ARE THE EFFECTS OF THE OCEAN ON THE TOPOGRAPHY OF AN ESTUARINE ENVIRONMENT—THE MAIDFORD RIVER

Gary Smith

McKinley High School, Washington, D. C.

In the past several years the Maidford River has been of great interest to SPSO students. My problem was to study the effects the ocean had on the topography of the Maidford. Profiling was the technique used to study the topography. By contouring the results, the mouth of the Maidford appeared to fluctuate, while the river itself seemed to remain unchanged.

METALLURGY: THE GROWING OF THE CRYSTAL

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Metallurgy is the art and science which is concerned with metals and their alloys. It deals mainly with the recovery of the metal from its ore, its refining, alloying with other metals, forming, fabricating and testing, and a study of the relation of alloy constitution and structure to mechanical properties.

The major aspect dealt with here is the formation of metal crystals through 1 of 3 methods. Although the Czochralski and horizontal methods are discussed, it is the Bridgman technique that is of the greatest importance because of its simplicity. The metal lead was used because of its low melting point.

Even though seeds of lead crystals were formed, it can clearly be seen that the technique used in this paper needs to be refined. Some of these adjustments are that the metal needs to be melted and the crucible should be a sealed one. A clear crucible would be helpful.

Being able to recrystallize metal is a basis for the hot and cold workings in industry. When the technique is carried out correctly it is a useful tool for mankind and industry.

MODULATION OF HUMAN LECTIN-INDUCED LYMPHOCYTOTOXICITY

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The effects of EDTA, cold, colchicine, cytochalasin B, and trypsin were studied on an autologous lectin-induced lymphocytotoxicity system. The various agents were added to an *in vitro* system containing ^{51}Cr-labeled target red blood cells, effector peripheral human blood lymphocytes, and a lectin. The degree of cytotoxicity was determined by the amount of ^{51}Cr release.

We found that cold, by lowering the metabolic activity of the cell, inhibited cytotoxicity. EDTA inhibited cytotoxicity due to disruption of cell-to-cell contact. Both colchicine, which disrupts microtubules, and cytochalasin B, which disrupts microfilaments, were observed to inhibit cytotoxicity. The addition of trypsin resulted in increased cytotoxicity, presumably due to the uncovering of new receptor sites on the cell surface.

These experiments indicate that necessary requirements for autologous lectin-induced lymphocytotoxicity include a metabolically active cell, cell-to-cell contact, intact microtubular and microfilament systems, and adequate numbers of appropriate surface receptors for the inducing agent.

REVIEW

Chemical Communication in Insects[1]

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ABSTRACT

Many aspects of insect behavior are regulated by minute amounts of chemicals with highly specific action. Insects may use such compounds in finding mates, locating food or suitable sites of oviposition, recruiting workers, warning others of attack, and driving off enemies. As research on the nature and mode of action of these materials progresses, applications in insect pest management programs will increase.

Insects are greatly dependent on chemical signals throughout their lives. They find food and mates and suitable locations for oviposition by following chemical cues from other insects and from their surroundings. We can think of numerous examples. For instance, a column of ants carrying crumbs from a picnic table back to the ant hill is guided by the chemical trail laid down by the foraging ants that first discovered the food supply. When a swarm of honey bees, *Apis mellifera* L., is ready to move to a new nesting location, scouts are sent out first. When they return, the swarm subsequently follows these scouts to the new site, depending for guidance on chemicals the scouts give off. Unless the swarm senses the presence of the queen through her scent, however, many of the bees turn back (Morse, 1963). The presence of a worker bee which has been treated with a queen bee extract fools the swarm enough that most of the bees will fly to the new site without a queen (Avitabile *et al.*, 1975); several different chemicals may be involved in this swarming behavior. Mosquitoes use chemical cues to find humans to bite and suitable waters for egg-laying. Perhaps the most dramatic examples of chemical communication are found in the various steps in insect mating. In this area the chemicals can be extremely effective in minute amounts. It has been reported that a single female introduced pine sawfly, *Diprion similis* (Hartig), in the five days of her adult life, was responsible for attracting the 11,000 males that were caught on the sticky board surrounding her cage (Coppel *et al.*, 1960).

It may be argued that such uses of chemical cues do not constitute communication in the strictest sense. Nevertheless, for want of a better term, "chemical communication" has become fairly standard usage. In a developing

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field of interest such as this, many terms are coined to convey specific meanings and those that are found useful by others eventually gain acceptance. "Semiochemical" is such a term, meaning a chemical that carries a message (Law and Regnier, 1971). Originally this term referred only to naturally-occurring substances, but chemicals from other sources are now often included.

Natural semiochemicals may be pheromones, allomones, or kairomones, three other recently-coined words. A *pheromone* (Karlson and Lüscher, 1959) is a substance secreted or emitted by one member of species that brings about a response in another member of the same species. The attractant emitted by that female sawfly I mentioned is a sex pheromone. Pheromones are intraspecific semiochemicals, acting within a species, affecting members of the same species. *Allomones* and *kairomones*, on the other hand, are transspecific (or interspecific); the emitter and the receiver belong to different species; transspecific semiochemicals have been called *allelochemics* (Whittaker, 1970; Whittaker and Feeny, 1971). An *allomone* is "a chemical substance, produced or acquired by an organism, which, when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological reaction adaptively favorable to the emitter" (Brown, 1969). The reaction produced by a *kairomone* benefits the recipient of the message rather than the emitter (Brown *et al.,* 1970). Thus, the scent of a skunk would be considered an allomone, since it repels the skunk's enemies, while the rabbit odor that enables a fox to locate its prey is a kairomone, since the receiver (the fox) is benefitted by the message. These terms are not mutually exclusive. A bark beetle sex pheromone, frontalin, is used by some bark beetle predators to locate their prey (Vité and Williamson, 1970); thus, it is both a pheromone and a kairomone.

Insect hormones, which act internally within a single insect, do not fit into the scope of this discussion.

Examples of Non-Chemical Communication

I do not want to give the impression that all insect communication involves semiochemicals, for this is far from being the case. Chemicals are probably the most widely used means of insect communication, but many other methods are also known. Firefly lights, for example, can be mating signals. The males fly about, flashing in a pattern characteristic for their species, and females on the ground or on low perches flash answers back. A male receiving a correct answer to his flashed message, with the appropriate flash length and delay, comes closer and repeats his pattern. This dialogue continues until the male reaches the female. There is not always a happy ending, however, for some predatory females seem to have broken the code used by other species and have been observed to attract males of other species by mimicking the appropriate female response and then to devour the male when he gets within range (Lloyd, 1975).

Both a rat mite, *Laelaps echidnina* Berlese, (Bruce, 1974) and a bark beetle parasite (Richerson and Borden, 1972) have been reported to find their hosts by sensing the emitted infrared radiation.

Some planthoppers find their mates by means of vibrations. Females on a rice stem vibrate their abdomens, and males elsewhere on the plant sense the vibrations and respond if the frequency is right (Ichikawa *et al.,* 1975).

Some male cicadas attract females by their stridulation, or singing. This can be unfortunate for them, for one parasitic fly locates cicadas by means of this song, with the result that males are more frequently parasitized than females (Soper *et al.*, 1976).

Perhaps the best known non-chemical means of communication is the honey bee waggle dance which foraging workers use to inform other workers of the location of a food source. The straight-line portion of the dance pattern indicates the direction, while the waggle frequency shows the distance (von Frisch, 1946, 1974). Odors are also involved in relaying this information (Gould, 1975).

Many other examples of non-chemical means of communication could be cited, but that would be beyond the scope of this paper. My purpose is to outline some of the many roles semiochemicals play in the lives of insects and in their interactions with other insects and with their environment. More detailed information can be obtained from some of the numerous comprehensive reviews on various aspects of the subject, as, for example, Birch, 1974a; Eisner, 1970; Jacobson, 1972. Although a goodly number of these chemicals have been identified, many others are recognized only through their action. Our information in this area is far from complete.

Insect Olfaction

To receive the messages carried by these chemicals, insects must have some means of detecting them. Although a few pheromones seem to be detected by tasting, in most cases the detectors, or chemoreceptors, are found on the antennae (Schneider, 1974). Since it appears that the process of chemoreception by insect antennae is comparable to that whereby odors are detected by the human nose, the process is often referred to as insect olfaction (Schneider, 1969). Hopefully, studies of insect responses to semiochemicals will lead to increased understanding of how we detect and discriminate between various odors. Conversely, progress in mammalian olfaction and gustation may contribute to the understanding of insect chemoreception.

Studies of insect olfaction rely greatly on the electroantennogram (EAG) (Schneider, 1957), which is a measurement of the electrical response of an antenna to a chemical stimulus. EAGs have great utility in studies on the nature and mechanism of action of pheromones and in the identification of pheromonal components (Arn *et al*., 1975).

Insects also have chemoreceptors that correspond to our taste buds, but gustation and general food attractants are not considered here.

Sex Pheromones

Up to now, insect sex pheromones are the insect semiochemicals that have received the most intensive study. Naturalists have believed for a long time that scents were responsible for mate-finding by various moths. As long ago as 1690, for example, John Ray, a biologist, noted several male moths, *Biston betularia* (L.), fluttering around a cage in which a female of the species had just emerged from her chrysallis; in reporting this, he suggested that the scent of the female had attracted the males from outside (Mickel, 1973). Early collectors added rare specimens to their collections by using caged females as lures. The French naturalist Fabre (1900) published observations on various male moths attracted through open windows by caged female moths; one species of moth responding in this way had not been found in the area in twenty years.

By the early 1900's, then, it was well known that attractive materials given off by female moths of many species attract males and that these materials are very specific in their action. In moths, this material is usually produced by glands in the female abdominal tip, and females emitting the attractant lift the tips in a characteristic position referred to as "calling". The gypsy moth, *Lymantria dispar* (L.), is one insect that has received intensive study. Even in 1914, traps baited with live female gypsy moths were being used to locate new infestations of this forest defoliator and to delineate the extent of existing infestations (Collins and Potts, 1932). However, all females are not equally attractive, they live only a few days, and they are available for only a short time, so there are many factors limiting the utility of live female gypsy moth traps. In addition, there is always the possibility that a live female could escape and start a new infestation. By 1920 it had been found that extracts of female abdominal tips could be used in place of the live females, thus overcoming many of these obstacles. The discovery in 1944 (Haller *et al.*, 1944) that hydrogenation of the extract increased its stability and attractiveness was another forward step. Nevertheless, without a knowledge of the chemical composition of the attractant, entomologists were dependent upon live insects to obtain the lure extracts for gypsy moth survey traps. The supply of these insects in the USA is very erratic; for several years, moths were collected in Spain to prepare extracts for USDA survey traps.

Widespread attempts at identifying the attractant pheromones of different insects continued, but it was not until 1959 that the identification of a sex pheromone, that of the silkworm moth, *Bombyx mori* (L.), was reported (Butenandt *et al.*, 1959). This accomplishment had required 20 years of careful experimentation, and half-a-million female pheromone glands were used. By an involved series of separation steps about 6 mg of pure substance was isolated from the extract of these glands. Microchemical studies (hydrogenation and permanganate oxidation) and synthesis showed this pheromone to be (*E,Z*)-10,12-hexadecadien-1-ol, called bombykol.

One requirement in pheromone identification studies is an adequate supply of insects, both as a source of pheromone and also as test subjects for use in following the isolation and purification steps. Butenandt and his group had insects readily available—silkworms have been "domesticated" for 4000 years at least. With other insects this has been a severe limitation. Unless a successful method for rearing has been developed, wild insects must be used and these may be available only for a limited time—sometimes not more than a week or two each year. Rearing insects is no easy task. Problems with diet and disease are but two of the many difficulties encountered.

Another requirement for successful pheromone identification is a good method of bioassay. Insects, like all living things, are extremely complex mixtures of chemicals, and to sort out the minute amount of unknown material from the relatively massive amounts of other similar and dissimilar chemicals, it is necessary to have some means of monitoring each step in a separation to locate the fraction containing the active material. The product of the pheromone gland of the female silkworm moth attracts males and causes intense excitation, with wing vibration and a circling sort of dance. Butenandt used the wing vibration in his bioassay, and his "unit of attraction" was defined on the basis of the concentration of material that would cause at least 50% of the males in a cage to start this vibration when a glass rod dipped into the solution was introduced. We now know that the attractive component (or components) in the pheromonal emission of a female moth is not necessarily the same as that causing stimulation, and the search for attractant pheromones cannot depend exclusively on a stimulatory response as a method of bioassay. The ultimate test of an attractant is a field test, and thus far there have been no reports of field tests with bombykol. After all, the silkworm is not a pest insect, so bombykol has not been needed for survey trapping, which is the means by which other pheromones have received the most extensive testing. It seems probable that bombykol is indeed an attractant as well as a stimulant, but this point needs clarification.

In the sixteen years since the discovery of bombykol was announced, many other attractant pheromones have been identified. This has been accomplished largely through advances in analytical methodology, such as microchemical techniques and instrumentation for chromatographic separations and spectrophotometric measurements. By now, more than 70 compounds have been identified as attractant pheromones, and several other compounds that are attractive seem to be pheromones but have not been rigorously proven to be present in the insect (Inscoe and Beroza, 1976).

Since the response of male moths to

''calling'' females is generally very specific, it had been thought that attractant pheromones would be species—specific. This is not necessarily so. (*Z*)-11-Tetradecen-1-ol acetate, for example, has been identified in the attractant pheromone of 10 different moth species and is attractive in the field to males of 12 other species, making 22 species in all thus far. In 13 of these 22 species, another compound is also needed for maximum attractancy.

This requirement of more than one compound for attraction is rather typical of the complexities we are encountering as we learn more about the sex pheromones (Silverstein and Young, 1976). Very often, precise ratios of two or more components are found to be needed. With many moths that require two pheromonal components, the compounds are closely related chemically. For example, they may be opposite geometric isomers, differing only in the arrangement of atoms around a double bond (Beroza *et al.*, 1973a); positional isomers, having double bonds in different positions on the carbon chain (Meijer *et al.*, 1972; Tamaki *et al.*, 1971); homologues (Nesbitt *et al.*, 1975); or compounds with different functional groups, such as an alcohol and the corresponding acetate (Roelofs *et al.*, 1975), or an aldehyde and an acetate (Kochansky *et al.*, 1975b).

The European corn borer, *Ostrinia nubilalis* (Hübner), provides an interesting example. This insect was introduced into North America from Europe in broom corn shipments two or three different times between 1909 and 1914 and was first established in areas where brooms were manufactured. It spread fairly rapidly, though, and now it is a pest in most of the major corn-producing regions east of the Rocky Mountains. In the early 1970's scientists in Iowa reported that male moths responded to (*Z*)-11-tetradecen-1-ol acetate found in the female pheromonal emission and that the opposite isomer, (*E*)-11-tetradecen-1-ol acetate, inhibits this response; so that in the presence of more than 15% *E* isomer, no moths are attracted by the *Z* isomer (Klun and Robinson, 1971). Despite this inhibition, it was soon found that small amounts (about 3%) of the *E* isomer are needed for attraction (Klun *et al.*, 1973). In New York, on the other hand, it was found that it is the *E* isomer that is attractive to the males and is the major component of the female pheromone (Roelofs and Comeau, 1971; Kochansky *et al.*, 1975a). Cooperative trapping studies (Klun and Cooperators, 1975) have recently shown that in most of Europe (Austria, Germany, Roumania, Poland, France, Spain, and Switzerland) and of North America (Iowa, Missouri, Minnesota, Nebraska, Georgia, Wisconsin, and several Canadian provinces), males respond to the *Z* isomer containing small amounts of the *E*, while in Italy, Netherlands, and New York, males prefer the other blend—*E* with a little *Z*. In Pennsylvania and New Jersey both kinds of response are found. This seems to indicate that the New York strain was brought to North America in a shipment from Italy and for some reason has not spread very far, while the major strain in North America came from elsewhere in Europe. Where the habitats of the two strains overlap, there seems to be practically no hybridization.

In addition to the attractant pheromones, other compounds may have a marked effect on the number of insects caught in attractant traps. I have already mentioned the inhibitory effect of large amounts of the minor isomer of the European corn borer pheromone. Other compounds drastically reduce trap catches of other insects, sometimes completely eliminating the attractancy even when present only in trace amounts. Compounds of this type have been called inhibitors or masking agents. Other compounds have been found that do not appear to be attractive in themselves but increase the effectiveness of a lure; these have been referred to as synergists. Compounds of both types have been found in pheromonal emissions.

Now we are finding that the terminology we have been using may be misleading (Kennedy, 1972). It is possible that some of the compounds we consider attractant pheromones because they enable males coming from a distance to locate the females may not be attractants at all but may be acting as stimulants, activating the males to fly up-wind and search for the females; those that blunder into the traps in the course of their searching get caught. Other compounds seem to be true attractants, causing direct orientation to the source of emission. We are also finding that some of the so-called synergists do not act merely to increase the effectiveness of an attractant but play a definite role in the response of male moths, such as increasing the frequency of alighting (and thus increasing the probability of being caught in a trap) (Cardé *et al.,* 1975). Similarly, a compound that reduces trap catches when it is exposed in a trap with a lure and is therefore classed as an inhibitor may actually increase trap catches when disseminated over the surrounding area (Mitchell *et al.,* 1974; Rothschild, 1974). It is obvious that we know very little of how the sex pheromones work, and more behavioral studies are needed to clarify the function of various pheromone components and the point in the mating sequence at which each acts.

In most moth species that have been studied, the female attracts the male for mating. In fact, in some species the females have no wings (Tvermyr, 1969) and must rely completely on their attractant pheromone to bring males to them. Attractant pheromones may act over long distances. In one instance, a marked male moth was recaptured in a trap, baited with synthetic pheromone, 7.5 km from where he had been released the previous day (Kochansky *et al.,* 1975b). Lepidopteran attractants that have been identified thus far have been long-chain (10–18 carbon atoms) compounds of relatively simple structure, usually with one or two double bonds. Acetates are the compounds reported most frequently; numerous alcohols and aldehydes are also active. A ketone, (*Z*)-6-heneicosen-11-one (Smith *et al.*, 1975), a hydrocarbon, 2-methylheptadecane (Roelofs and Cardé, 1971), and an epoxide, *cis*-7,8-epoxy-2-methyloctadecane (the gypsy moth pheromone, called disparlure) (Bierl *et al.*, 1970), have also been identified as lepidopteran pheromones. In insect orders other than the Lepidoptera, the situation seems more complex. Attractant pheromones are produced sometimes by the male, sometimes by the female, and a wide variety of structures have been found.

In the boll weevil, *Anthonomus grandis* Boheman (a coleopteran), for example, the male produces a pheromone that is attractive to females but that also attracts other males early and late in the season. It may therefore also be regarded as an aggregation pheromone, bringing insects of both sexes together. Four components, all having cyclic structures, have been identified, and some combination of at least three of these is necessary for attraction (Tumlinson *et al.,* 1969).

Bark beetles, which are very destructive in evergreen forests, also emit aggregating pheromones (Borden, 1974). In various species of *Dendroctonus*, in which the male is monogamous, a female finding a suitable tree starts boring a mating chamber and emits a pheromone, which, in combination with volatile materials from the tree, is very attractive to males, as well as being an aggregating pheromone (Renwick and Vité, 1969; Wood, 1970). In *Ips* spp. the polygamous male is the one that starts boring into the tree and gives off a pheromone advertising for mates as well as attracting other males to attack the tree (Wood, 1970). This is a great oversimplification, for bark beetles of both sexes emit a variety of pheromones.

The sex pheromones I have mentioned thus far have served to bring insects together for mating. Other sex pheromones may act to make the female more receptive. Some male butterflies have complex glands (''brushes'' or ''hairpencils'') that are the source of aphrodisiac pheromones that release mating behavior in the female (Birch, 1974b). Male queen butterflies, *Danaus gilippus berenice* (Cramer), brush ''hairpencil dust'' onto flying females to induce them to alight (Pliske and Eisner, 1969). Certain male cockroaches give off "seducin," a volatile substance that has not been identified, which induces the female to feed on a liquid oozing from the male tergal glands and makes her receptive to mating (Roth and Dateo, 1966).

Trail Pheromones

Pheromones other than sex pheromones are also known and are particularly important in the lives of social insects. Among these are the trail pheromones, which are used by ant or termite foragers returning to the nest with food. Ants heading home extrude their sting and deposit streaks of chemical on the path. Other workers following the trail reinforce it as long as food is found, but workers returning empty-handed no longer deposit the pheromone and the trail soon fades away. Ants will follow an artificial trail drawn with contents of the pheromone gland from a single ant and mill around in confusion at the end of the trail (Wilson, 1963). Up to now, very few trail pheromones have been isolated and identified, although many insects have been shown to use such pheromones. Of the ten compounds that have been reported, six are used by one ant species; these are fatty acids with 6 to 12 carbon atoms (Huwyler *et al.*, 1973). The other four known trail compounds are an alcohol, (*Z,Z,E*)-3,6,8-dodecatrien-1-ol (Matsumara *et al.*, 1968), an ester, methyl 4-methylpyrrole-2-carboxylate (attalure) (Tumlinson *et al.*, 1972), a macrocyclic hydrocarbon, 12-isopropenyl-1,5,9-trimethyl-1,5,9-cyclotetradecatriene (Birch *et al.*, 1972), and a heterocyclic compound, 3-butyl-octahydro-5-methylindolizine (Ritter *et al.*, 1973). All together, four ant and eight termite species have been found to use one or another of these ten compounds.

Alarm Pheromones

These trail pheromones recruit workers for food-gathering. Other pheromones may recruit for defense; some of the alarm pheromones have this function (Wilson, 1975b). Alarm pheromones (alerting pheromones) are wide-spread in the social insects and elicit a variety of responses, such as excitement, flight, attraction, and attack. Probably more of these compounds have been identified than of any other type of pheromone, but in many cases the function of the individual compounds has not been elucidated, and all the components found in an alarm secretion may not necessarily be pheromones. Like most trail pheromones, alarm pheromones are short-lasting in their effects and act only over short distances. These properties are reflected in their molecular size. To act rapidly and be dissipated equally rapidly, these compounds must be relatively volatile, and most alarm pheromones have molecular weights between 100 and 200 (Wilson, 1970), with 5–12 carbon atoms; they include hydrocarbons, ketones, aldehydes, and esters. There is much less species specificity in alarm pheromones than in other pheromones and sometimes several species respond to the same alarm pheromone. This is not surprising, for a threat to one insect often threatens others also. Unlike other pheromones, which are usually present only in trace amounts, alarm pheromones are often present in fairly high concentrations.

Responses to alarm pheromones are many and varied. Often insects are attracted by low concentrations. At higher concentrations, response is related in large part to the organization of the colony. With semisocial insects such as the bed bug, *Cimex lectularius* L., (Levinson *et al.*, 1974) or with ants that live in small, loosely-organized colonies (Regnier and Wilson, 1969) in places like rotting logs, the alarm pheromones act as an early warning signal for evacuation and they scatter in all directions. These insects are not well-equipped for defense, and flight is the only practical strategy for them. For other ants in tightly organized colonies, increasing concentrations of the alarm pheromone stimulate the insects to attack. The red harvester ant, *Pogonomyrmex barbatus* (F. Smith), is one of these. Workers of this species will attack a wad of cotton treated with 4-methyl-3-heptanone, a component of its alarm pheromone, and when a small drop of this compound was placed on one of the ants, it was immediately chased and attacked by near-by nest mates (McGurk *et al.*, 1966). Longer exposure to this pheromone brings on still another reaction, that of digging and carrying away pebbles. It has been suggested, but not proven, that this is because the pheromone also acts as a signal to rescue nest mates buried in a cave-in.

The pheromones I have discussed so far—sex pheromones, trail pheromones, and alarm pheromones—are the ones with which we are most familiar, but pheromones with many other actions are known.

Miscellaneous Pheromones

There are oviposition pheromones, for example. Some mosquito larvae give off a substance stimulating oviposition by the adult females (Kalpage and Brust, 1973). The advantage of this is clear; a location where eggs have successfully hatched has proven its suitability, while an untried pool may be only temporary and may dry up before eggs laid there can hatch. This pheromone would be an example of an oviposition-stimulating pheromone. Oviposition-deterrent pheromones are also known. After laying an egg, female black cherry fruit flies, *Rhagoletis fausta* (Osten Sacken), or apple maggot flies, *Rhagoletis pomonella* (Walsh), drag their ovipositors about the fruit and deposit a substance that discourages other females from laying in the same fruit (Prokopy, 1972, 1975). Some parasitic wasps similarly mark host eggs or larvae in which they have laid eggs (Vinson and Guillot, 1972; Guillot *et al.*, 1974). By preventing over-parasitization, this gives the parasite larvae a chance to develop without competition.

The mixture of fatty acids given off by some dead ants can also be regarded as a pheromone (Wilson *et al.*, 1958). These fatty acids act as a signal to the workers to carry the dead ant out of the nest and put it onto the refuse pile. A live ant that has been daubed with some of these chemicals receives exactly the same treatment. No matter how often it returns to its nest, it gets carried back to the dump; the process is repeated over and over, and the hapless ant isn't allowed to remain in its nest until the "odor of death" finally wears off.

Other pheromones are involved in nest and colony recognition (Hubbard, 1974), brood tending (Glancey *et al.*, 1970; Bigley and Vinson, 1975), thermoregulation (Ishay, 1972), and a host of other phases of insect life.

There is even evidence for a "cannibalism pheromone" that causes diploid honey bee larvae to be eaten by the workers (Dietz and Lovins, 1975). The pheromones considered thus far have all been "releaser" pheromones—they bring about an immediate release of some action in the receiver. Another group of pheromones are the "primer" pheromones that trigger a physiological change in the receiving insect. The result of such a change is particularly noticeable in the desert locust, *Schistocerca gregaria* (Forskål), and other locusts. In dry years these insects resemble ordinary green grasshoppers and tend to remain solitary, poking around for food by themselves. The rains of wet years, however, stimulate hatching of eggs in large numbers, and it seems (Gillett, 1975; Nolte *et al.*, 1973) that a gregarization pheromone excreted by the young hoppers accumulates in large enough quantities to stimulate a color change from green to yellow and black and a change in habit from preferring a solitary existence to becoming part of a devasting swarm. Among other primer pheromones are ones that control caste changes in termites (Lüscher, 1961; Nagin, 1972) or prevent development of a new queen bee as long as there is an active queen in the hive (Butler *et al.*, 1961). Some of the various functions of pheromones are summarized in Table I.

Table I.—Insect pheromones.

Sex Pheromones
Attractants
Inhibitors
Stimulants
Aphrodisiacs
Aggregation Pheromones
Trail Pheromones
Alarm Pheromones
Others
Oviposition stimulant
Oviposition deterrent
Territorial marking
Brood tending
Necrophoric
Colony recognition
Thermoregulation
Caste determination
Inhibition of queen rearing

Allelochemics

Up to this point we have been considering pheromones—chemicals used by insects for communication with other members of their own species. Insects also employ other semiochemicals, the allomones and the kairomones. With these materials, communication is interspecific—between members of different species. It should be remembered that these classifications are for convenience and are not exclusive. A pheromone can also be an allomone or a kairomone.

Allomones

Allomones, by definition, are interspecific semiochemicals that evoke a reaction that benefits the emitting organism in some way. By way of illustration, let us consider some slave-maker ants. At least thirty-five species of ant are known to depend to some extent on slave labor by other ants (Wilson, 1975a). Slave-maker workers raid a nest of another species and capture worker pupae, which they carry back to their own nest. When adults emerge from these captured pupae, they accept their new home and instinctively carry on the necessary housekeeping tasks—foraging for food, tidying the nest, and caring for the eggs and larvae of their captors. Some slave-makers rely on brute force in their raids and kill resisting workers to capture the pupae they are after. A few species have been found to be more subtle. Workers of *Formica subintegra* Emery and *F. pergandei* Emery have enlarged glands that contain relatively enormous amounts (up to 10% of the entire body weight) of three esters—decyl acetate, dodecyl acetate, and tetradecyl acetate (Regnier and Wilson, 1971). These compounds are effective alarm pheromones. A small amount of an applicator stick poked into the edge of a nest of this species caused the entire colony to become highly excited and attracted most of the workers, who tried to attack the stick. These same esters also cause alarm in the nests of ants that are used as slaves. In this case, however, the result is panic; when the raider ants discharge these compounds, the excited workers run about aimlessly and scatter in all directions, leaving the nest free for the raiders to get the pupae they are seeking. The scattered ants do not return to their nest, probably because the odors of these esters, which are less volatile that most alarm substances, remain around the area for a long time. These three esters, then, act both as alarm pheromones, summoning raiding workers to the attack, and also as allomones, producing a reaction of panic in the attacked species that aids the attackers.

Many of the defensive secretions used by insects for their protection can be regarded as allomones. These secretions, which an insect emits when it is disturbed, to protect itself from predators, come in many forms—a fine spray or jet, a slow ooze, or even a foam (Eisner, 1970). A great variety of chemicals have been identified as defensive compounds (Weatherston and Percy, 1970), including aliphatic acids, esters, aldehydes, ketones, hydrocarbons, quinones, steroids, and terpenoid compounds. Most defensive secretions contain several different compounds; analysis of the secretion from a tenebrionid beetle showed the presence of more than fifty compounds (Tschinkel, 1975). Some compounds are irritants or repellents, others are distasteful to attackers, and others appear to make the secretion more effective by increasing spreading or penetration. (Venoms and other toxicants from insect stings or bites are not generally classed as defensive secretions.) Defensive materials may act as repellents or irritants, or they may set up into a sticky material that interferes with the predator's actions. Some bombardier beetles use a reaction much like that involved in an aerosol can of hot shaving lather (Aneshansley *et al.,* 1969). A hydroquinone reacts with hydrogen peroxide and the hot reaction products are sprayed out as a fine mist that reaches temperatures of 100°C. The benzoquinones in the reaction mixture are strong irritants, so the result is both chemical and thermal heat. A well-known defensive secretion is formic acid, which gets its name from its occurrence in a number of formicine ants, where it was first reported (though misidentified) in 1670 (Wray, 1670). It is found in many insect species; in some it may also serve as an alarm pheromone. Many other alarm secretions are also defensive secretions, rallying attackers as well as acting as a repellent to invaders.

Some predators have learned to circumvent the defensive spray of their insect prey. Grasshopper mice have been observed to subdue beetles that spray irritating quinones from a gland in the abdominal tip by holding them head-up so all the secretion is ejected onto the ground (Eisner *et al.,* 1963). The mouse can then eat the beetle with impunity.

The defensive spray of some insects contains hydrocarbons such as undecane that may function by interfering with chemoreceptors on the predators' antennae (Blum and Brand, 1972). Insects often rely on their antennae to locate their prey, and if the prey insect can disable these antennae, it has a good change of getting away.

A defensive chemical need not be aimed at the predator directly. A Brazilian wasp suspends its small paper nest by a narrow stem, 2–3 cm. long. Wasp larvae are very attractive to ants, but the adult wasps smear the suspending stem of the nest with a repellent substance that foraging ants will not pass (Jeanne, 1970). With this protective barrier, the larvae are safe in the nest, and the adults need not leave a wasp on guard while they are away.

Although the viscous or sticky materials in defensive secretions might be regarded as being a mechanical rather than a chemical defense, the repellent and irritant components are clearly allomones; they are chemicals conveying a message that is of benefit to the emitter.

Flower scents may attract insects in search of nectar. In gathering the nectar, the insect picks up pollen, which it then brushes off onto other flowers. The flower scents are therefore allomones, because the action elicited by the scent results in pollination of the flowers. Some Mediterranean orchids have a different twist (Kullenberg, 1961, 1973). Their scent appears to contain some of the same compounds that are in the female sex pheromone of certain wasps. The flowers themselves look enough like wasps to fool males attracted and stimulated by the scent, and in attempting to mate, the males are brushed by the pollinia and unwittingly act as pollen carriers.

Kairomones

Unlike the allomones, kairomones carry a message that results in benefit to the receiver of the message, rather than the emitter. Often these are scents used by parasites or predators to find suitable prey (Vinson, 1976). Relatively few insect kairomones have been identified thus far; these include a number of hydrocarbons that stimulate host-seeking behavior by various parasites of the corn earworm, *Heliothis zea* (Boddie) (Jones *et al.,* 1971, 1973). Heptanoic acid in the frass from potato tuberworm, *Phthorimaea operculella* (Zeller), larvae is another; it elicits heightened searching behavior by a parasitic wasp (Hendry *et al.*, 1973).

Lactic acid in human sweat is one of the cues used by some mosquitoes to locate someone to bite (Acree *et al.,* 1968). It therefore would also be considered a kairomone.

Codling moth, *Laspeyresia pomonella* (L.), larvae are attracted by a substance found in apple skins, α-farnesene (3,7,11-trimethyl - 1,3,6,10 - dodecatetraene) (Sutherland and Hutchins, 1972). This same compound stimulates oviposition by adult female codling moths (Wearing and Hutchins, 1973). Thus, it seems to ensure that eggs are laid where the hatching larvae will find suitable food. Other oviposition stimulants in plants are known. Allyl isothiocyanate, found in cabbages and similar plants, stimulates oviposition by some insects (Gupta and Thorsteinson, 1960; Traynier, 1965). Certain glucosides from olives stimulate oviposition by the olive fruit fly, *Dacus oleae* (Gmelin) (Girolami *et al.,* 1975), but if the olives are damaged, a substance in the olive juice acts as a repellent, thus preventing eggs from being laid where chances of hatching are reduced. The glucosides can stimulate the females to lay eggs in molded paper mounds where they are easily accessible; they may thus simplify mass rearing of the fly.

Another substance of plant origin, not yet identified, aids a larval parasite of the artichoke plume moth, *Platyptilia carduidactyla* (Riley), (Bragg, 1974) in locating its host. A substance in the sap of artichoke plants that have fresh wounds such as might be made by the moth larvae attracts this parasitic wasp and stimulates it in its search for its larval host. This material illustrates again the overlapping that may be encountered in classification. Since the artichoke plants are benefitted by parasitization of the larvae feeding on them, the material is an allomone. On the other hand, it aids a parasite in locating its prey and acts as a kairomone.

Polyphemus moths, *Antheraea polyphemus* (Cramer), will not mate unless oak leaves are present. The reason for this puzzling observation was traced to a volatile compound, (*E*)-2-hexenal, given off by the leaves (Riddiford, 1967). Female moths will not ''call' and release their attractant pheromone in the absence of this compound, and males will not mate unless the females ''call''. Accordingly, there is no mating unless suitable larval food is available in the form of oak leaves. (*E*)-2-Hexenal is therefore a kairomone. Interestingly, this aldehyde is found in the defensive secretions of a number of insects; in the secretion of some cockroaches, the compound is sufficiently pure to induce moth mating even in the absence of oak leaves (Riddiford, 1967).

Up to this point I have given a brief run-down on a few of the myriad ways in which chemicals are involved in the interaction of insects with their surroundings. In interactions between insects and man, man often comes out the loser. Insects are often vectors of disease. Besides being painful, some insect stings can cause dangerous allergic reactions. Insects can destroy valuable trees, make damaging inroads on farmers' crops, and consume a large portion of the harvest when it is in storage. To cut down on insect depredations, man uses a varied arsenal of weapons, among which are the semiochemicals. As we reduce our reliance on pesticides, we will have to rely more on alternative methods of control and find new ways of using non-toxic chemicals such as these chemical messengers.

Synthetic Materials

One approach has been to search for effective repellents and attractants by empirical screening of chemicals (Beroza, 1970). A large number of compounds are tested for activity; other compounds related to those showing some activity are then synthesized and tested. By following leads in this way, we eventually may come across a compound with sufficient activity to have practical applications. Deet, *N,N*-diethyl-*m*-toluamide, the most effective repellent for mosquitoes and biting flies that we have up to now, was found in this way (McCabe *et al.*, 1954). Effective attractants for a number of insects, including the

Japanese beetle, *Popillia japonica* Newman (McGovern *et al.,* 1970), the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Beroza *et al*., 1961), and some yellowjacket wasps (Davis *et al.,* 1972), have also been developed by this route. These synthetic attractants do not occur naturally in the insects, although methyl eugenol, the oriental fruit fly, *Dacus dorsalis* Hendel, attractant (Steiner, 1952), has been found in some leaves and flowers (Kawano, 1968; Fletcher *et al.,* 1975). Concentrations of these synthetic lures that are needed for attraction are much greater than those for the attractant pheromones. For example, traps for the Mediterranean fruit fly are usually baited with over a gram of trimedlure (*tert*-butyl 4(or 5)-chloro-2-methylcyclohexanecarboxylate) (Howell *et al.,* 1975), while amounts of the gypsy moth pheromone used in survey traps have ranged from 10 μg to 10 mg, and traps baited with 1 ng of this pheromone have caught moths even after 3 months exposure (Beroza *et al.,* 1971).

Applications

As we have seen, chemicals that affect insect behavior at many stages in their development are now known, and as analytical methodology improves, additional compounds are being reported with increasing frequency. The question now is, "How can we use these compounds?"

An obvious use of attractants is in traps, which I have mentioned already. Baited with attractant pheromones or synthetic lures, these have become an indispensable tool in surveys to locate new insect infestations, to estimate the size of existing infestations, to determine the most effective timing for application of control measures, and to check on the effectiveness of these controls. Last year, for example, 17,000 traps baited with attractants for three fruit flies were deployed around various southern ports of entry to guard against importation of these flies. Last fall a few Mediterranean fruit flies were found in these traps in one county in California (Anon., 1975), and control measures were quickly initiated to prevent the spread of the incipient infestation. Thousands of other traps for the gypsy moth, the Japanese beetle, pink bollworm, *Pectinophora gossypiella* (Saunders), and other insects are being used similarly in surveys for these pests.

Design of an effective trap is a research project in itself (e.g., Kennedy, 1975). Each insect has its own behavioral idiosyncracies that must be taken into account. Factors such as trap color, trap height, trap shape, size and position of trap entrance, and location of lure must all be considered. The trapping agents may be mechanical baffles or sticky materials that prevent escape, water or another liquid that drowns the insects, a toxicant, or an electrocutor grid. All in all, traps come in a bewildering array of sizes and shapes.

Theoretically, it should be possible to control small insect infestations by putting out traps in sufficient numbers. Up to now, however, this has not proved practical. With the sex attractant traps, for example, only adults, and only those of one sex, are caught. (Boll weevil pheromone traps are exceptions, since the sex pheromone also acts as an aggregation pheromone and males as well as females are trapped.) Since it is usually the larvae that do the damage to the crops, reliance on these traps for immediate crop protection would be something like locking the barn door after the horse had been stolen. Nevertheless, trapping of adults will cause a reduction in the next generation, provided that there is no migration into the area. Promising results have been obtained in some trapping tests (e.g., Beroza *et al.*, 1973b; Trammel *et al.*, 1974) and mass trapping may eventually develop into a feasible procedure. Tests are now underway with several insects.

A related application is the use of pheromones to attract insects to insecticide-treated trap crop plots; this procedure was effective in tests against the boll weevil (Scott *et al.,* 1974; Hardee *et al.,* 1975).

At the present it appears that mating

disruption by general dissemination of a sex pheromone thoughout an area will be developed into a practical means of control more rapidly than trapping methods. Results in tests with a number of insects have been promising (e.g., Beroza, 1976; Roelofs *et al.*, 1976; Shorey *et al.*, 1976; Tumlinson *et al.*, 1976; Rothschild, 1975). Last summer, for example, a microencapsulated formulation of the gypsy moth pheromone was sprayed over 75 square miles in northeastern Maryland at a rate of 6 g/acre, with the result that mating of female gypsy moths was reduced by about 70% in the treated area. The mechanism behind such mating disruption is not yet clear. Perhaps the pervasive pheromone overloads the chemoreceptors in the males' antennae so that they no longer detect the females' pheromone; perhaps the concentration of the synthetic pheromone is high enough to mask the odor trails leading to individual females. It is quite possible that different mechanisms may be involved with different species. Pheromones affecting other phases of the mating process may be even more effective than the attractant pheromones with some insects, and in some cases compounds that are not pheromones may also act as mating disruptants. Air permeation with attractant inhibitors has disrupted mating of the European corn borer (Klun *et al.*, 1975) and the redbanded leafroller, *Argyrotaenia velutinana* (Walker), but dissemination of inhibitors has been ineffective with several other insects. This is an area where we have much to learn.

Trapping and mating disruption are but two potential applications of pheromones. As our knowledge increases, we should expect to find other ways of manipulating insects with their own chemical communication systems. For example, the aphid alarm pheromone, β-farnesene (7,11-dimethyl-3-methylene-1,6,10-dodecatriene), which is given off when an aphid is attacked, causes other aphids feeding nearby to drop off the plants as a way of rapid escape; it has been suggested that this behavior might be utilized for aphid control (Bowers *et al.*, 1972). Another type of pheromone with potential utility for insect management is the oviposition marking pheromone that deters repeated oviposition (Prokopy, 1972: Yamamoto, 1975); field application of partially purified pheromone produced by female *Rhagoletis cerasi* (L.) reduced infestation of treated cherries by nearly 80% (Katsoyannos and Boller, 1976). The brood-tending pheromone of the imported fire ant, *Solenopsis invicta* Buren, is still another prospect for use in control. Filter paper discs treated with the pheromone were rapidly carried into the nest by workers and treated as pupae; the pheromone may thus provide a means of introducing and localizing insecticide treatments within a colony (Bigley and Vinson, 1975).

Applications of other semiochemicals are also being explored. Release of parasitic wasps is proving to be one way of reducing corn earworm, *Heliothis zea* (Boddie) populations; in small field tests, distribution of kairomones of the corn earworm that stimulate host searching by *Trichogramma* spp. resulted in more even distribution of the released parasites and less dispersal away from the treated area (Lewis *et al.*, 1975; Jones *et al.*, 1976).

From all appearances, semiochemicals will prove to be most effective in combination with other methods of insect control. Attractants may be used to bring insects to an area where they can be killed with a toxicant or treated with a pathogen or a chemosterilant. Destruction of palm trees in Samoa was reduced by infecting the coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) population with a virus with the aid of traps baited with a synthetic lure (P. A. Maddison, personal communication), and some beetles infesting granaries have been inoculated with a protozoan infection by means of a pheromone-baited device (Schwalbe *et al.*, 1974).

A pilot test against the boll weevil has demonstrated the potential of integrated insect management through coordination of various suppression techniques, including the use of pheromones

(Hedin *et al.*, 1976). Late season insecticide treatments were used to reduce overwintering weevil populations. Removal of cotton plants after harvest destroyed food and shelter to cut down chances of survival of weevils that escaped the insecticide. Pheromone traps were used for monitoring throughout the test and were set out in the spring to catch emerging weevils. The release of male weevils treated with a chemosterilant dealt the final blow by ensuring that any surviving females would produce only infertile eggs. Despite some migration of weevils into the treated area from infested fields outside, the two-year program effectively eliminated the weevil from two-thirds of the experimental area.

As we learn more about insect semiochemicals and their behavioral effects, we can expect to find many new and imaginative ways of using them in insect management programs.

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Biological Notes on *Stenodynerus microstictus* (Hymenoptera: Eumenidae)

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ABSTRACT

The turret-building wasp, *Stenodynerus microstictus*, is active from May to October in northeastern Kansas and has aggregated nests in vertical river banks. Nests contain 1 to 17 brood cells provisioned with noctuid and gelechiid larvae. *S. microstictus*, reared in the laboratory, developed from an egg to an adult in about 19 days. *Trypoxylon* sp. (Sphecidae) uses abandoned nests of this eumenid as nesting sites.

Stenodynerus microstictus (Viereck), which constructs a "lacelike" nest turret (Fig. 1), has received limited treatment in the literature. Evans (1956) briefly examined its nest architecture and provisions in Pottawatomie County, Kansas, citing similarities to Isley's (1914) observations of the related species *S. papagorum* (Viereck). We relate further aspects of the biology of *S. microstictus*.

Methods

Observations were made from May to September, 1974, on the banks of the Kansas River, 14.5 km east of Lawrence, Douglas County, Kansas. In most cases, nests in lumps of soil were examined in the laboratory. Bleached flour was squeezed from a plastic bottle into nests to facilitate finding burrows in soil and cell provisions were preserved in Dietrich's (Kahle's) solution. Immature wasps selected for rearing were placed with cell provisions in vials closed with cotton plugs and held in darkness at room temperature.

Results

S. microstictus is active about nests from early May to early October (W. A. Hawkins, pers. comm.). Wasps begin leaving nests when direct sunlight first illuminates nesting sites (0900, August). One wasp observed during the entire period of activity outside the nest, left and returned to her nest 5 times in 1 day. She stayed away from her nest from 85 sec to several hours and her activity outside the nest ceased just before sunset, 1850.

The 19 nests which were studied were "loosely aggregated" in about 10 m² of vertical river bank 2.5 m high that faced northwest. A 50-cm bank overhang sheltered the nests, the burrow entrance of

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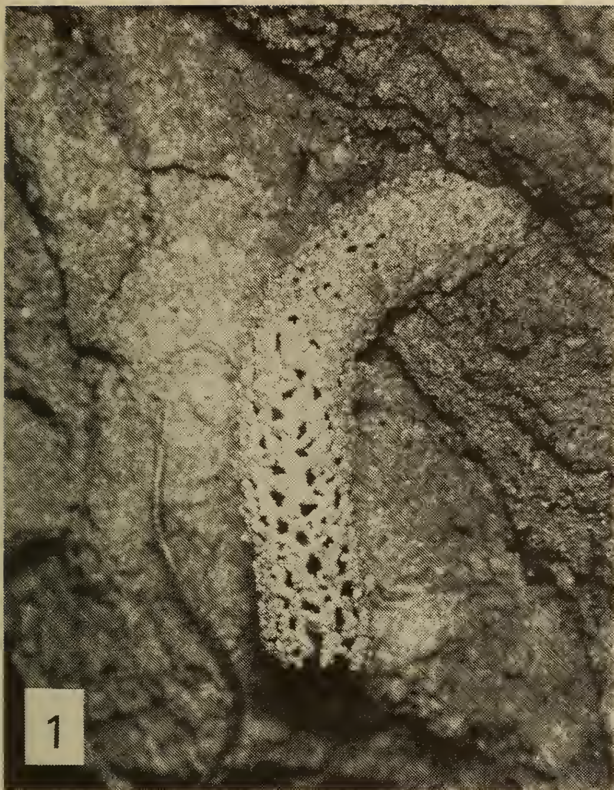

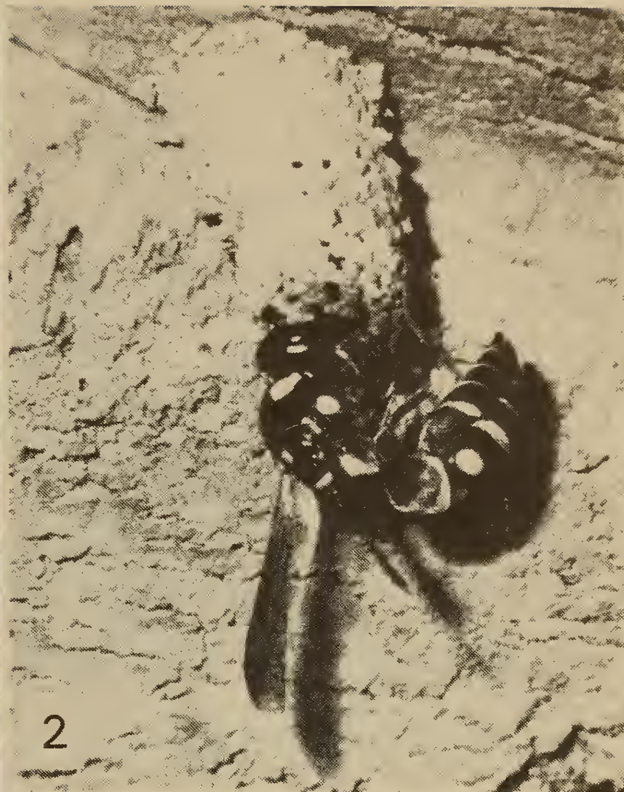

Fig. 1. Nest turret of *Stenodynerus microstictus*. Fig. 2. Female *S. microstictus* constructing a nest turret (photograph from a color slide taken by W. A. Hawkins).

each being within an indentation in the bank's hard, sandy soil. Nest entrances averaged 1.0 m below the top of the bank (range, 0.3 to 2.0 m; n = 12); the mean distance between nests was 12.5 cm (range, 2 to 100 cm; n = 12). Eight of the 19 nests were actively inhabited. The nearest other aggregation was about 40 m upstream. Nests of *S. microstictus* were dispersed among nests of other hymenopterans including *Lasioglossum (Dialictus) zephyrum* (Smith) (Halictidae), *Philanthus gibbosus* (Fabricius) (Sphecidae), and *Hylaeus binsinuatus* (Förster) (Colletidae) (Barrows, 1975).

Aspects of nest construction by 3 wasps nesting within 1 m^2 were observed. In constructing her nest, a wasp carries small bits of moistened soil with both her mouthparts and forelegs as she backs out of her burrow. She affixes soil to the rim of the burrow entrance with mouthparts alone, her legs supporting her at first on the bank and later on a lengthening turret (Fig. 2). As turret construction progresses, her abdomen curves up and behind the wall of the turret as a support against which soil bits are tamped into a rough lacework. During construction the wasp periodically backed into the turret and appeared to rest there for about 40 sec, entered the burrow for an average of 15 sec (range 5 to 20 sec; n = 27), or cleaned herself before flying towards the river (possibly to collect water), remaining away an average of 8 min (range, 2 to 10 min; n = 5). We observed that all excavated soil was used in turret construction; however, some soil which *S. microstictus* removes in digging burrows might be simply dumped out of the nest. Turrets are too short to be composed of all the soil excavated from nests.

Twice, other conspecific wasps attempted entering nests while wasps constructed turrets. This resulted in heated battles; the wasps fell to the foot of the bank biting and attempting to sting one another.

Provisions from 7 cells are listed in Table 1. About 35% of the provisions were desiccated. Larval miltogrammine sarcophagid flies were found among wasp

Table I.—Contents of cells of *Stenodynerus microstictus*.

Cell No.	Contents
1	Diptera: Calliphoridae: possibly *Phaenicia sericata* (Mg.)[1], 1 larva Hymenoptera[2], 1 egg Hymenoptera: Aculeata: probably Sphecidae[2], 2 larvae Lepidoptera: Noctuidae: *Charcoma nilotica* (Rogenhofer)[3], 2 larvae Lepidoptera[3], 4 eggs
2	Lepidoptera: Noctuidae: *C. nilotica*, 5 larvae
3	Lepidoptera: Noctuidae: *C. nilotica*, 3 larvae, 1 prepupa, 1 pupa
4	Hymenoptera: probably Sphecidae[2], 11 larvae Lepidoptera: Noctuidae: *C. nilotica*, 7 larvae, 1 prepupa
5	Hymenoptera[2], 1 prepupa
6	Lepidoptera: Noctuidae: *C. nilotica*, 6 larvae
7	Coleoptera: Curculionidae: Ceuterhychinae: near *Auleutes*[4], 3 larvae Lepidoptera: Gelechiidae[3], 2 larvae

[1] Determined by R.J. Gagné
[2] Determined by A.S. Menke
[3] Determined by D.M. Weisman
[4] Determined by D.M. Anderson

provisions. It is unclear whether these flies were parasites of the wasps or of the provisions and why calliphorids, sphecids, and curculionids were found in cells of *S. microstictus*.

Life cycle information is limited due to 63% mortality of *S. microstictus* immatures. Five were reared from larvae, with a maximum of 7 days spent in that life stage. The pupal stage lasted an average of 11.8 days (range, 9 to 14 days; n = 6). One male wasp was reared to adulthood from an egg of unknown age. It was an egg for 1 day; a larva, 6 days; a prepupa, 1 day; and a pupa, 11 days.

Some nests were more complex than those examined by Evans, although many had only 1 or 2 cells (Figs. 3, 4). On the average there were 4 cells per nest (range, 1 to 17 cells; n = 20 nests), with a mean cell length of 1.3 cm (range, 0.7 to 1.5 cm; n = 80 cells) and 0.5 cm in greatest diameter (range, 0.45 to 0.50 cm), tapering to 0.4 cm at either end. Most cell walls were coated with a thin, "silky," shiny substance. Cells were separated by thin soil partitions and were often in a series of 2 or 3. In the more complex nests (Fig. 5), cells were bunched along either side of the burrow, while simpler nests had them gathered only at the burrow's distal end. Distance from nest entrance to cells ranged from 0.5 to 12.0 cm. Burrow length averaged 5.7 cm (range, 2.0 to 12.0 cm, n = 20), the mean diameter being 0.4 cm (range, 0.35 to 0.4 cm). Burrows penetrated the bank more or less perpendicularly. The turrets shared the burrows' average diameter of 0.4 cm (range, 0.4 to 0.5 cm, n = 16) with mean length of 1.5 cm (range, 0.3 to 4.0 cm). Erosion probably decreased turret lengths because many had jagged ends. Two inhabited nests completely lost turrets.

Nest provisioning was observed at 1130. A female flew towards a nest entrance clenching an 8-mm caterpillar with her forelegs. After landing upon the turret, she used her fore- and middle legs to push the prey ahead as she advanced into the nest, bracing herself with her hind legs pressed against the turret's interior.

A *Trypoxylon* wasp landed upon a turret at 1530, August 20, chewed its outer surface near the proximal end for 30 min, and gained an opening large enough for entrance. The wasp was active inside the nest from 1630 to 1930 (dusk), frequently returning to the new opening to dump soil bits or make short flights. Excavation of this abandoned *S. microstictus* nest made 2 days later revealed that 1 cell contained an egg and 23 spiders. The egg was reared until death at the prepupal stage, which prevented a species identification. Hawkins (pers. comm.) reared *Trypoxylon* sp. from nests of *S. microstictus* at the same site. Olberg (1959) disclaims a hypothesis of turret building as a deterrent to parasites or "invaders", citing the frequent occurrence of both in the turreted euminine nests of his studies. The evidence here indicates the turret posed a barrier for the invading *Trypoxylon*, although further work is needed to evaluate effectiveness in this or other capacities.

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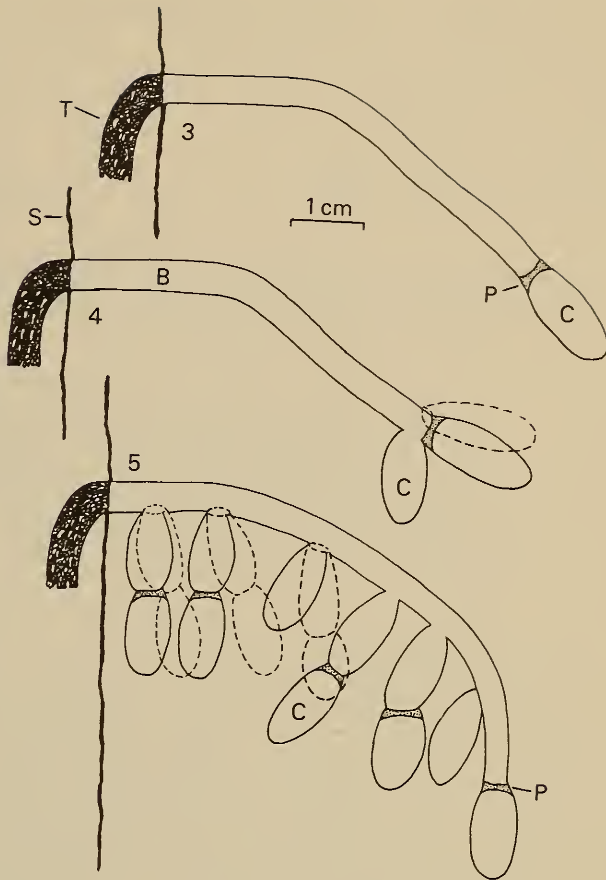

Figs. 3–5. Side views of nests of *Stenodynerus microstictus*: B, burrow; C, cell; P, plug of soil; S, surface of vertical river bank; T, turret.

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A Review of *Pseudorhizoecus* Green, with a Description of a Related New Genus (Homoptera: Pseudococcidae)

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ABSTRACT

The genus *Pseudorhizoecus* Green and its type-species *proximus* are redescribed; a lectotype is designated, and the diagnostic characters of *P. proximus* are figured. A new genus *Capitisetella* is proposed for *Pseudorhizoecus migrans* Green because the species has several features not known on *P. proximus*. A redescription of *C. migrans* is given and its diagnostic characters are illustrated.

Green (1933) described the genus *Pseudorhizoecus* for the new species *proximus* and *migrans* from Surinam (Dutch Guiana). Green considered the genus to be assignable to the Pseudococcidae and characterized it by the absence of both anal-ring setae and "beaded or areolated" structures present on the anal ring of related genera. After careful examination of all available material of *P. proximus* and *P. migrans*, including the types, I have found that both species have anal-ring setae. In the type-species, *P. proximus*, the anal ring has an inconsistent number of small setae and many isolated protuberances, many of which have apical spicules. In *P. migrans* the anal ring is very different; it has 6 obvious setae that are relatively consistent in size and location, and it lacks the protuberances found on *P. proximus*. Based on these differences and on characteristics of the antennae, leg spines, and body setae it is evident that *proximus* and *migrans* should be placed in different genera.

Genus **Pseudorhizoecus** Green

Pseudorhizoecus Green, 1933:55. Type-species: *Pseudorhizoecus proximus* Green, by original designation.

Body of female robust, about 1 mm. long. Antennae 5-segmented, weakly geniculate, terminal segment with slender, curved sensory setae. Eyes absent. Anal-lobe area undeveloped, without differentiating setae or sclerotization. Anal ring with few indiscriminately placed small setae, several cells and many oval protuberances. Legs with characteristic tibial and tarsal spines. Derm with crowded, slender, apically acute setae arranged in bands across segments, with few trilocular pores.

Adult male apterous, with 5-segmented antennae similar to female. Eyes absent. Legs well developed. Penial sheath and aedeagus strongly sclerotized, superficially resembling *Rhizoecus*. Derm with setae crowded in bands across segments as in female.

Discussion.—For a comparison of *Pseudorhizoecus* with the new genus *Capitisetella* see "Discussion" under that genus.

Pseudcrhizoecus proximus Green
Fig. 1–3

Pseudorhizoecus proximus Green, 1933:55.

Adult female: Broadly ovate. Length, 0.85–95 mm; width, 0.75–0.88 mm. Antennae closely spaced, moderately short, stout, tapering toward apex, average length of segments in microns: I, 28; II, 17; III, 14; IV, 11; V, 46; apical segment about 2 times as long as wide, with 4 very slender and 2 short sensory setae; all segments with numerous long, apically acute setae. Interantennal space less than width of segment I. Rostrum moderately stout, averaging 81μ long, 55μ wide; rostral loop reaching to or slightly beyond 2nd coxae. Cephalic plate and dorsal ostioles absent.

Legs well developed, fairly stout, elongate, with numerous setae, average length of segments of hind pair in microns: Trochanter, 51; femur, 111; tibia, 99; tarsus, 45; claw, 32; tibiae each with 1 pair stout spines on ventral surface near distal extremity; tarsi each with 2 pairs of elongate spines on ventral surface, the distal pair more

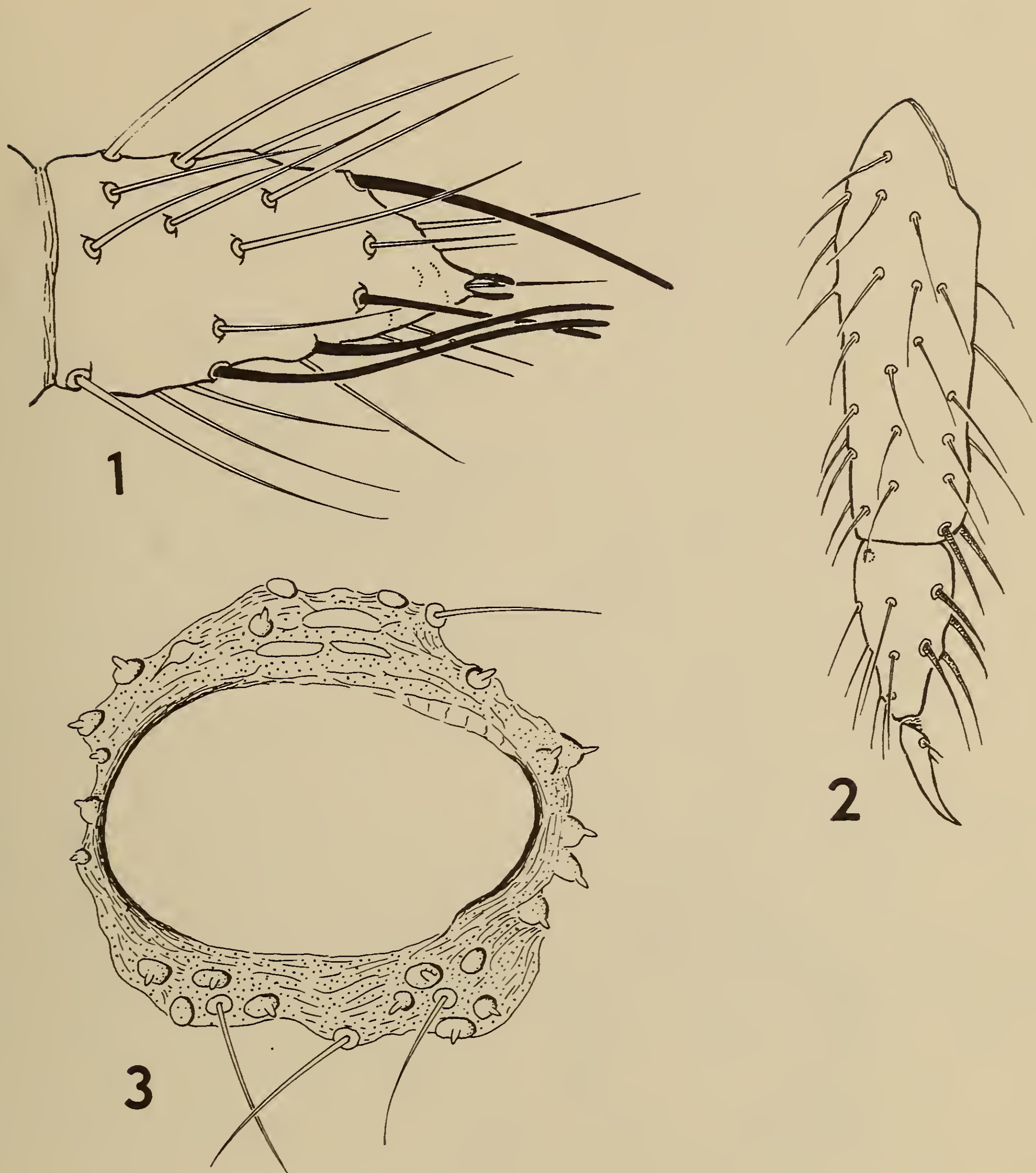

Fig. 1–3, *Pseudorhizoecus proximus*, ♀: 1, antennal segment V; 2, tibia, tarsus and claw of left hind leg; 3, anal ring.

setose, reaching beyond base of claw; digitules short, setose, not reaching half length of elongate, weakly curved claws.

Anal ring irregularly outlined, broader than long, about 52μ wide, strongly sclerotized, without elongate anal-ring setae but with 2–5 short setae about 15–17μ long, few cells, and 25–30 small oval protuberances, most with short, stout spicules. Derm without circuli, cerores, tubular ducts or disk pores; trilocular pores more numerous on venter of posterior abdominal segments and dorsally along borders of setal bands. Body setae slender, apically acute, 15–20μ long, crowded, some longer setae occurring ventrally.

Material examined.—Five slides containing 8 adult females, 2 adult males, 14 immature females, including the type female and cotype male, all from Surinam (Dutch Guiana), on *Coffea liberica*, 1931–33, G. Bunzli. In British Museum (Nat. Hist.). Since the type slide contains 3 females, and no type specimen was indicated by Mr. Green, I am designating the one ringed with ink on right side of slide as the lectotype.

Thirty-three additional specimens in the U. S. National Museum Collection represent new host and distribution records: Colombia: On *Coffea arabica*, 10-X-56, S. E. Flanders. Costa Rica: On *Musa paradisiaca* var. *sapientum*, 10-V-57, E. B. Dixon: Palmar, 24-VIII-60, L. Roth; Turrialba, on *Theobroma cacao*, 29-VII-56, Neal Weber. Ecuador:

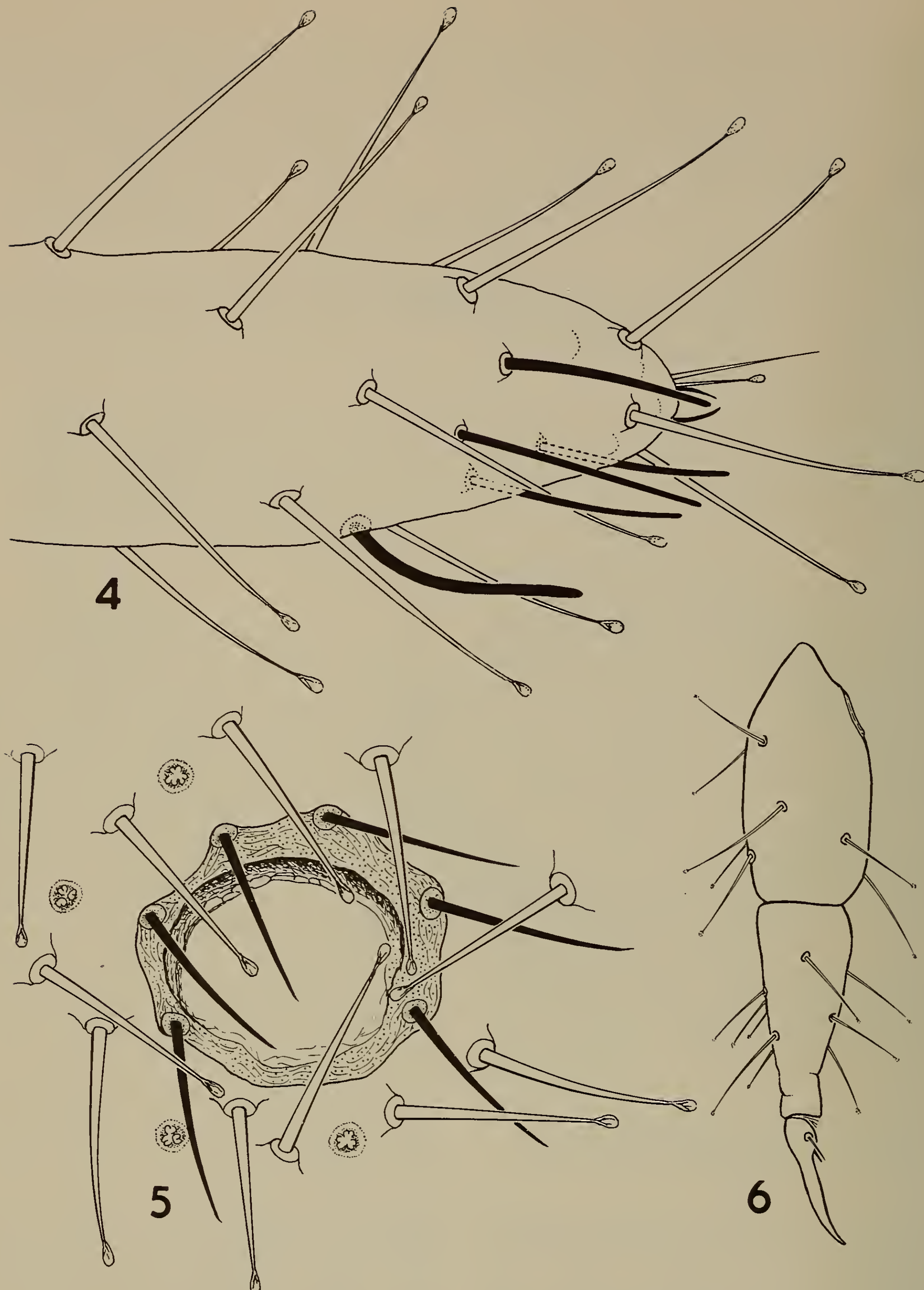

Fig. 4–6, *Capitisetella migrans*, ♀: 4, terminal portion of antennal segment III; 5, anal ring; 6, tibia, tarsus and claw of left hind leg.

Pichilingue, on coffee, 1-X-44, E. J. Hambleton. Guatemala: Retalhulew, on coffee, 16-V-45, E. J. Hambleton.

Capitisetella Hambleton, new genus
Type-species: *Pseudorhizoecus migrans* Green.

Body of female weakly pyriform, averaging 1 mm. long. Antennae 3-segmented, terminal segment with slender sensory setae. Eyes absent. Anal-lobe area simple, undeveloped without differentiating setae or sclerotization. Anal ring at posterior apex, strongly sclerotized, with 6 regularly placed, slender setae and few elongate cells. Legs stout, with long, capitate setae but without tarsal or tibial spines. Derm with scattered, stout capitate setae and trilocular pores.

Adult male apterous with 3-segmented antennae similar to female; apical segment with 20–25 slender sensory setae of different sizes, and about as many capitate setae. Eyes absent. Legs well developed. Penial sheath and aedeagus heavily sclerotized, similar in general conformation to that of *Pseudorhizoecus*. Derm with few trilocular pores and capitate setae across segments.

Discussion.—*Capitisetella*, with anal-ring setae, 3-segmented antennae, capitate setae and without leg spines is easily separated from *Pseudorhizoecus*. *Capitisetella* and *Pseudorhizoecus* are similar to *Brevicoccus* Hambleton from Brazil, but *Brevicoccus* differs by having 4-segmented antennae, 12–15 anal-ring setae and multilocular disk pores. The structural arrangement of the anal ring in *Brevicoccus* is similar to *Rhizoecus*. The striking morphological differences in *Brevicoccus*, *Capitisetella* and *Pseudorhizoecus* indicate a departure from the more characteristic rhizoecine form.

Capitisetella migrans (Green), new combination
Fig. 4–6

Pseudorhizoecus migrans Green, 1933:56.

Adult female: Ovate, posterior area slightly produced. Length, 0.97–1.25 mm; width, 0.63–0.72 mm. Antennae widely spaced, average length of segments in microns: I, 50; II, 23: III, 105; apical segment about 3 times as long as wide, with 5–7 slender, variable, weakly falcate sensory setae, all segments with capitate setae. Interantennal space about equal to length of segment III. Rostrum stout, about 105μ long, 91μ wide; rostral loop reaching to 2nd coxae. Cephalic plate and dorsal ostioles apparently absent.

Legs well developed, robust, elongate, length of segments of hind pair in microns: Trochanter, 62; femur, 116; tibia, 82; tarsus, 71; claw, 44; tibiae and tarsi without spines, with capitate setae; claws narrow, weakly curved; digitules very short, setose, not reaching half length of claw.

Posterior abdominal area narrowed toward apex, with no anal-lobe development or differentiating setae. Anal ring simple, wider than long, about 50μ wide with 6 slender setae about 25–28μ long; cellular structure indistinct, in preadult female few cells visible below anterior pair of setae. Derm setae variable in size, longest about 45μ, more abundant ventrally. Circulus, disk pores and tubular ducts absent. Trilocular pores almost circular in outline, more numerous than body setae, sparse ventrally between legs and intersegmentally.

Material examined. —Holotype adult female, 1 adult male, 8 additional females, 24 immature females, from roots of *Coffea liberica* and grasses, Surinam, 1931–45, G. Bunzli. In British Museum (Nat. Hist.). Ten additional specimens including 2 males in process of moulting recorded from roots of grass, Guyana (British Guiana), R. Mazaruni, 31-VIII-35, N. A. Weber. Colombia: On coffee, 10-X-56, S. E. Flanders; Cucuta, on *Panicum maximum*, 10-VI-75, Jenner. In U. S. National Museum.

Acknowledgment

I thank Dr. D. J. Williams, British Museum (Natural History), London, for the loan of type material.

Reference Cited

Green, E. E. 1933. Notes on some Coccidae from Surinam, Dutch Guiana, with description of new species. Stylops 2(3): 49–58.

Four New Species of *Aegialia* (s. str.) (Coleoptera: Scarabaeidae) From California and Nevada Sand Dunes

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ABSTRACT

Four new species of North American *Aegialia* (*magnifica*, *crescenta*, *hardyi*, and *concinna*) are described. A key to the North American species of *Aegialia* (s. str.) and illustrations of habitus, genitalia, and other morphological details are presented.

Current research on the ecology of sand dune areas in the western United States (principally in California and Nevada) is being conducted by Dr. Alan Hardy, California Department of Agriculture, Sacramento, and several coworkers. Members of the Scarabaeidae form a large segment of the beetles associated with sand dunes; several undescribed species have been collected including the four new *Aegialia* species described here.

Many of the dune systems being studied are under pressure from recreational and commercial interests, and the resulting use of the dunes often destroys them from the natural history point of view. Attempts are being made to have at least some areas of these dune systems preserved, and the presence of endemic species is one lever that can be used toward this end. For that reason we are describing these 4 species of *Aegialia*, each of which is apparently restricted to a particular set of dunes.

The North American species of *Aegialia* have not been studied as a whole since Brown's 1931 revision of the genus. We have modified Brown's key to species of *Aegialia* (s. str.) to include the new species described here. Brown did not illustrate male genitalia. We have examined the male genitalia of all described species of *Aegialia* (where males are available) and include illustrations of those of the new species.

Brown's (1931) classification of the North American members of the Aegialiini resulted in the establishment of 2 genera, *Aegialia* Latreille and *Micraegialia* Brown. *Aegialia* is divided into 4 subgenera: *Leptaegialia* Brown, *Anomalaegialia* Brown, *Psammoporus* Thomson, and *Aegialia* (s. str.). The 4 species described here all belong to the latter subgenus.

All illustrations presented in this paper were prepared by Michael Druckenbrod, Smithsonian Staff Artist. The scanning electron microscope time for this paper was supported in part by the University of Maryland Center of Materials Research, Department of Mechanical Engineering and Electron Microscope Central Facility, College Park, Maryland.

Key to species of North American *Aegialia* (s. str.)

1. Pronotum with basal marginal line strong, entirely visible (fig. 1) 2
   Pronotum with basal marginal line absent or interrupted (fig. 2) 9
2. Hind tibial spurs short, broad, foliaceous (fig. 11) 3
   Hind tibial spurs slender, somewhat spatulate (fig. 9) 6
3. Elytral striae feebly impressed, indistinct; apex of body extremely broad,

convex; hind tibia with single, longitudinal row of tubercles on inner margin; southern California .... *convexa* Fall

Elytral striae distinctly impressed; apex of body not extremely broad or convex; hind tibia with double row of tubercles; most of U. S. and southern Canada 4

4. Color pale brown to medium reddish brown .... *conferta conferta* Horn

Color dark brown or nearly black 5

5. Pronotum finely, sparsely punctured; length 3.4 to 3.6 mm .... *conferta nigrella* Brown

Pronotum with strongly impressed, coarse punctures; length 3.6 to 4.2 mm .... *conferta punctata* Brown

6. Hind tibia without complete obliquely transverse ridges, a single longitudinal row of small tubercles present on inner margin, outer margin with irregular, large tubercles (fig. 9) .... *blanchardi* Horn

Hind tibia with at least one complete obliquely transverse ridge, tubercles entirely lacking or only one or 2 present (fig. 12) 7

7. Color pale red; head smooth, lacking tubercles, granules or coarse punctures (fig. 1) .... *magnifica*, n. sp.

Color dark brown to nearly black (except *concinna*); head rough, with either coarse punctures, or granules, or both 8

8. Length less than 3.6 mm; color pale brownish yellow; head granulate with some coarse punctures (fig. 4) .... *concinna*, n. sp.

Length more than 3.7 mm; color dark brown to nearly black; head coarsely punctured, not granulate (fig. 2) .... *crescenta*, n. sp.

9. Hind tibial spurs foliaceous; length 3.0 to 3.7 mm .... *opifex* Horn

Hind tibial spurs slender, somewhat spatulate (fig. 13) 10

10. Pronotum nearly impunctate, some fine, indistinct punctures on disc .... *arenaria* (F.)

Pronotum coarsely punctured 11

11. Hind tibia with a complete, strong ridge at apical 2/3 (fig. 16) ...... *hardyi*, n. sp.

Hind tibia without a complete ridge, sometimes without a partial ridge 12

12. Pronotum densely, coarsely punctured throughout .... *latispina* LeConte

Pronotum lacking punctures anteriorly and laterally, or punctures, if present, fine and indistinct 13

13. Pronotal punctures coarse basally, fine and indistinct apically and laterally ... . *crassa crassa* LeConte

Pronotal punctures fine basally, apical and lateral areas impunctate .... *crassa insularis* Brown

Aegialia (Aegialia) magnifica, new species

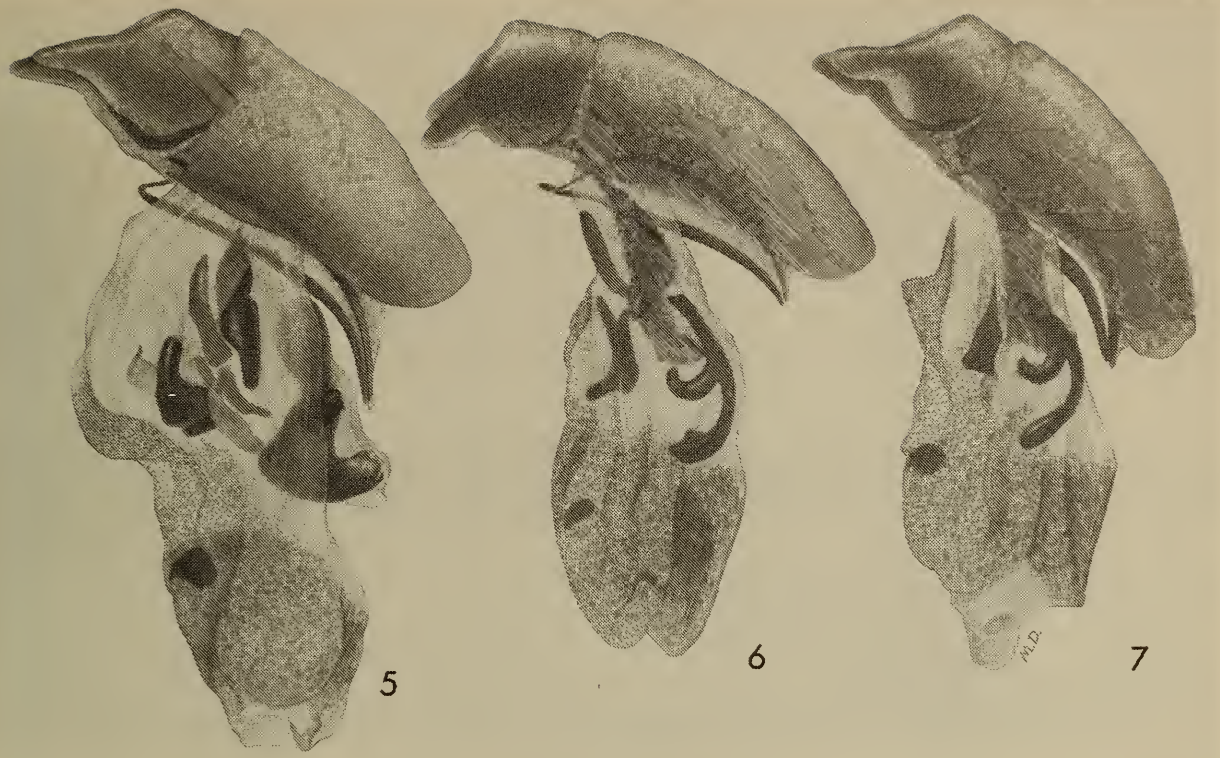
Holotype.—♂, length 5.40 mm, greatest width 2.85 mm. Form convex, oval, very broad posteriorly (fig. 1). Pale red; mouthparts and ventral surface yellowish red. Head smooth, shiny, finely alutaceous, fine punctures separated by a diameter or less, becoming coarser and denser at anterolateral angle; clypeus very feebly emarginate medially, anterior margin evenly reflexed. Pronotum smooth, shiny, surface barely perceptibly alutaceous, fine punctures separated by less than to 3 times a diameter, lateral fovea absent; base with marginal line distinct, entire. Elytron smooth, shiny, punctures on intervals very fine, separated by 2 to 5 times a diameter, intervals flat; striae feebly impressed, finely punctured, punctures separated by 2 times a diameter. Metasternum shiny medially, becoming densely punctured with intermixed fine and coarse punctures laterally. Functional wings absent. Abdominal sterna densely, coarsely punctured, punctures separated by less than a diameter; apical sternum with elongate, median depression. Middle tibia smooth with strong, complete ridge at basal ¼, and strong, complete ridge present medially; hind tibia broad apically, with incomplete ridge at basal ⅓, strong, complete ridge present at apical ⅔, surface smooth with fine, indistinct punctures (fig. 12); tibial spurs weakly spatulate (fig. 13); tarsus about ¾ as long as tibia. Genitalia as in fig. 5.

Allotype.—♀, length 5.55 mm, greatest width 3.0 mm. Similar to holotype except apical abdominal sterna without median impression.

Type-material.—Holotype, Nevada, Nye Co., "Big Dune", Amargosa Desert, 2500′, IV-29-1974, Hardy & Eichlin (at light) (USNM 73838). Allotype, same data as for holotype (USNM). Paratypes, 348, locality same as for holotype, dates are as follows; 12-I-1972, 11-X-1972, 17-X-1972, 20-XI-1972, 19-XII-1972, 15-I-1973, 29-III-1974, 19-IX-1974, 28-IV-1975; collectors are as follows; F. G. Andrews and A. R. Hardy, Derham Giuliani, Neal Rulien: ecological data available is "sifting sand." Paratypes in collection of USNM, California Academy of Sciences, Alan Hardy, Neal Rulien and Henry Howden.

Variation.—Length ranges from 4.40 to 5.90 mm, width from 2.48 to 3.25 mm.

Figs. 1–4, habitus of *Aegialia* species. Fig. 1, *A. magnifica*; fig. 2, *A. crescenta*; fig. 3, *A. hardyi*; fig. 4, *A. concinna*.



Figs. 5–7, male genitalia of *Aegialia* species. Fig. 5, *A. magnifica*; fig. 6, *A. crescenta*; fig. 7, *A. hardyi*.

Remarks.—*A. magnifica* is the most distinctive species of North American *Aegialia* (s. str.) presently known. The red color, usually large size, and smooth dorsal surface are very characteristic, and even small examples are not easily confused with any other species. The presence of a distinct marginal line on the pronotal base causes *magnifica* to go to the *blanchardi* section of the key, but the male genitalia and hind tibiae indicate a close relationship to *crescenta*, n. sp., and *hardyi*, n. sp.

Aegialia (Aegialia) crescenta, new species

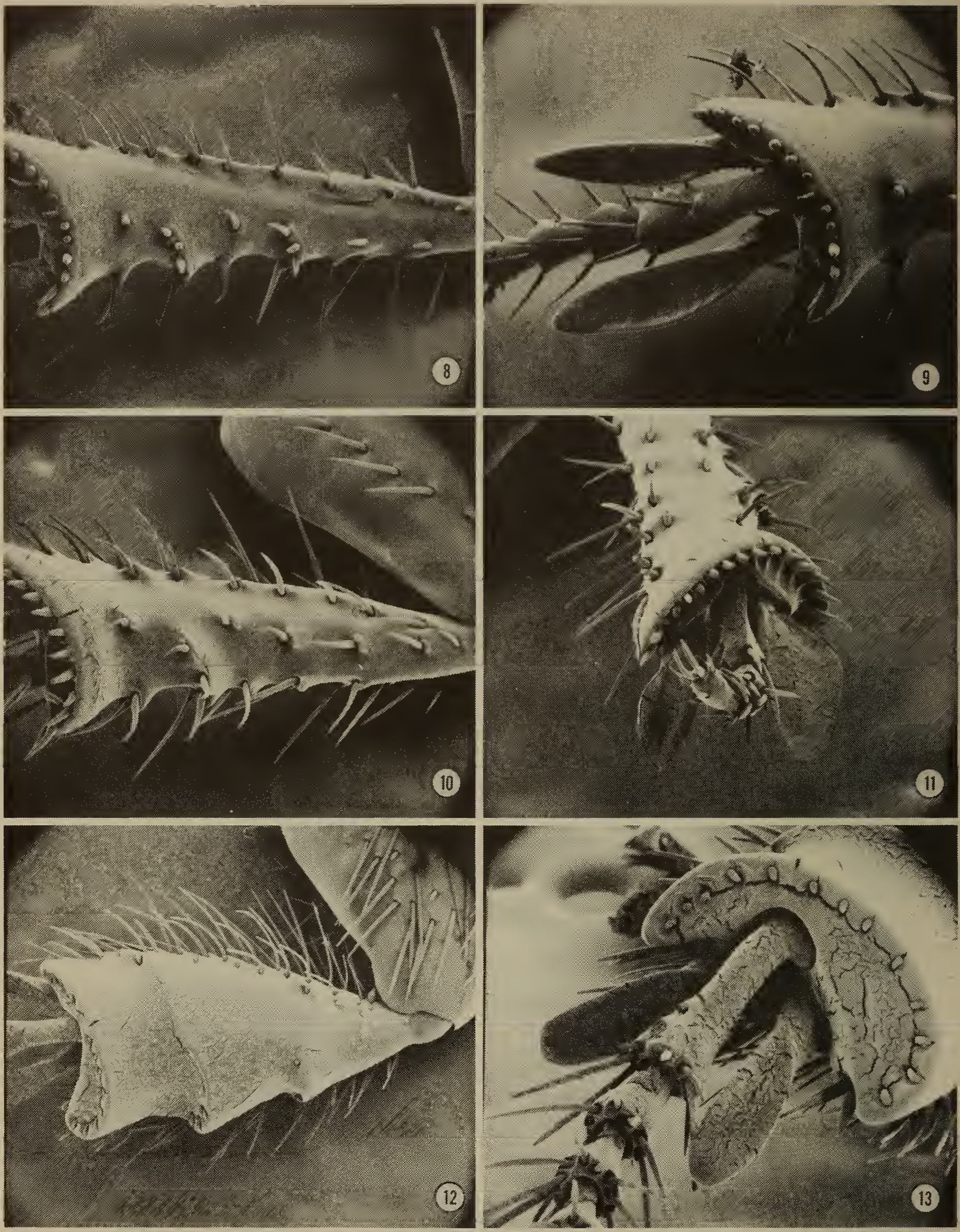
Holotype.—♂, length 4.25 mm, greatest width 2.40 mm. Form convex, oval (fig. 2). Dark reddish brown; ventral surface, legs and mouthparts pale yellowish brown. Head shiny, with band of coarse, nearly contiguous punctures from basal portion of clypeus to vertex; apical portion of clypeus less coarsely punctured, apical margin feebly emarginate medially, feebly reflexed. Pronotum smooth, shiny, disc with indistinct, feebly impressed furrow extending from base nearly to anterior margin, midline narrowly impunctate, rest of pronotum with coarse, sparse punctures separated by less than 1 to 3 times a diameter, feeble lateral fovea present; base with marginal line distinct, entire. Elytron smooth, shiny, intervals flat, punctures on intervals in single, slightly irregular, median row, separated by less than to 3 times a diameter; striae distinctly impressed, coarsely punctured, punctures separated by a diameter. Metasternum densely, finely punctured medially, intermixed fine and coarse punctures present laterally. Functional wings absent. Abdominal sterna strongly alutaceous, densely punctured; apical abdominal sternum with oval, median depression. Middle and hind tibiae and apical spurs as in figs. 14, 15. Genitalia as in fig. 6.

Allotype.—♀, length 4.60 mm, greatest width 2.55 mm. Similar to holotype except apical abdominal sternum without median depression.

Type-material.—Holotype, Nevada, Nye Co., Crescent Dune, 12-II-1976, Fred G. Andrews and Alan R. Hardy (USNM 73839). Allotype, same data as for holotype except date IV-24-1975 (USNM). Paratypes, 187, locality same as for holotype, dates differ as follows; 10-II-74, v-IV-75, 24-IV-75: some collected by Derham Giuliani. Paratypes in collections of USNM, California Academy of Sciences, Alan Hardy, and Henry Howden.

Variation.—Length ranges from 3.75 to 5.00 mm, width from 2.05 to 2.70 mm. The dorsal surface is somewhat alutaceous in some specimens, and the midline of the pronotum sometimes lacks any trace of a longitudinal furrow and may be sparsely punctured.

Remarks.—*A. crescenta* most nearly resembles *hardyi*, n. sp., and it is possible that these are merely disjunct



Figs. 8–13, hind tibiae and spurs of *Aegialia* species. Figs. 8 and 9, *A. blanchardi*; figs. 10 and 11, *A. conferta*; figs. 12, and 13, *A. magnifica*.

populations of a single species. However, because of the presence of a distinct marginal line on the pronotal base of *crescenta*, the sparse pronotal punctation of that species, and the genitalic differences (figs. 6, 7), we prefer to consider them as distinct species despite the absence of intermediate populations. Of the previously described species, *latispina* is most similar in appearance, but the hind

Figs. 14–17, hind tibiae and spurs of *Aegialia* species. Figs. 14 and 15, *A. crescenta*; figs. 16 and 17, *A. hardyi*.

tibia of *latispina* is of a completely different type than that of *crescenta*, as are the male genitalia.

The specific name is a neolatin noun referring to the type locality.

Aegialia (Aegialia) hardyi, new species

Holotype.—♂, length 4.50 mm, greatest width 2.38 mm. Description as for *crescenta* except differences noted as follows: head with vertex punctured; pronotal punctures coarse, dense, separated by a diameter or less, punctures present on midline, basal marginal line not visible in dorsal view (fig. 3), hind tibia and spurs as in figs. 16, 17: male genitalia as in fig. 7.

Allotype.—♀, length 5.10 mm, greatest width 2.60 mm. Similar to male except apical abdominal sternum without median depression.

Type-material.—Holotype, Nevada, Churchill Co., Sand Mountain Dunes, 16-IX-1974, Fred G. Andrews and A. R. Hardy (USNM 73840). Allotype, Nevada, Churchill Co., Sand Mountain, 13-II-1973, Derham Giuliani (CAS). Paratypes, 16, same data as for holotype and allotype except as follows; Nevada, Churchill Co., Sand Mountain, 12 mi. S., 20 mi. E. Fallon, 28-II-1974. Paratypes in collections of USNM, California Academy of Sciences, and Alan Hardy.

Variation.—Length ranges from 4.33 to 5.10 mm, width from 2.25 to 2.60 mm.

Remarks.—See comments under description of *crescenta*. *A. hardyi* resembles *latispina* LeConte but the hind tibiae of *latispina* are tuberculate and lack any complete ridges. We take pleasure in naming this species for Alan Hardy in view of his active interest in the ecology of sand dunes and his efforts toward preserving this habitat.

Aegialia (Aegialia) concinna, new species

Holotype.—♀, length 3.52 mm, greatest width 1.80 mm. Form convex, elongate (fig. 4). Pale brownish yellow, ventral surface mostly paler than dorsum. Head mostly granulate with some close, coarse punctures, vertex smooth; apical margin of clypeus reflexed, barely perceptibly emarginate medially. Pronotum smooth, shiny, coarsely punctured, punctures separated by a diameter or less; base with distinctly visible marginal line. Elytron smooth, shiny, punctures on intervals nearly invisible, arranged in a single irregular row; striae deeply impressed, coarsely punctured, punctures separated by twice a diameter. Metasternum smooth, shiny medially, alutaceous with coarse punctures laterally. Functional wings absent. Abdominal sterna shiny, faintly alutaceous, finely punctured; apical and preapical sterna fused medially. Middle tibia slender, with a weak, incomplete ridge at basal ¼ and strong, complete ridge at middle; hind tibia slender, with incomplete ridge at basal ⅓ and incomplete ridge at apical ⅔, surface smooth, lacking punctures; tibial spurs slender, feebly spatulate.

Type-material.—Holotype, California, Fresno Co., 18 mi. SW Mendota, Sec. 15 T16S R13E, 27-II-1975, G. Andrews, E. L. Paddock and A. J. Gilbert collectors (USNM 73841). Paratypes, 3, same data as for holotype. Paratypes in collections of USNM and Alan Hardy.

Variation.—Length ranges from 3.33 to 3.52 mm, width from 1.75 to 1.80 mm.

Remarks.—The small size, pale color, and slender, smooth hind tibiae distinguish *concinna*. No close relationship with any known species of *Aegialia* (s. str.) is apparent, and the lack of males makes genitalic comparisons impossible. The presence of a completely visible basal marginal line on the pronotum places *concinna* in the *blanchardi* section of the key but there is no phyletic significance to this association.

Reference Cited

Brown, W. J. 1931. Revision of the North American Aegialiinae (Coleoptera). Canadian Entomol. 63: 9–19, 42–49.

NEW FELLOWS

Lewis A. Gist, Director, Division of Science Manpower, Natl. Science Foundation, in recognition of his continuing leadership and contributions to science education at all levels, both in the U. S. and abroad. *Sponsors*: George W. Irving, Jr., Kelso B. Morris.

Thomas B. Glazebrook, Director of Watershed & Minerals Area Management, U. S. Forest Service, in recognition of his contribution to soil and water conservation on the National Forests, with particular reference to regional and national leadership of forest land management programs designed to maintain or enhance soil productivity and water quality. *Sponsors*: Richard H. Foote, R. R. Colwell.

William R. Heyer, Curator, Division of Reptiles and Amphibians, Smithsonian Institution, in recognition of his research on the systematics of leptodactylid frogs and especially his contributions to studies on tadpole ecology. *Sponsors*: Richard H. Foote, Ashley B. Gurney.

Jack R. Leibowitz, Professor of Physics, Catholic Univ., in recognition of his contribution to solid state physics, and in particular his researches on electron-phonon interaction, the electronic properties of metals and superconductivity including recent investigations on nonequilibrium effects and spatial variation of the order parameter in superconductors. *Sponsors*: James F. Goff, Ralph P. Hudson.

Stanley I. Warshaw, Director, Center for Consumer Product Technology, NBS, in recognition of his leadership and effective administration of a major Government program to develop and apply methods for the objective assessment of the performance, safety, energy efficiency and life-cycle performance of consumer products. *Sponsors*: Jacob J. Diamond, Jacob Rabinow.

REPORT OF TELLERS COMMITTEE

Election of Officers for 1977–1978:

President-elect:	Mary H. Aldridge
Secretary:	Kelso B. Morris
Treasurer:	Alfred Weissler
Managers-at-Large:	Harvey Alter
	Walter Shropshire, Jr.

Potomac Division, American Phytopathological Society ELECTED

Metropolitan Washington Chapter of the Society for General Systems Res. ELECTED

Potomac Chapter, Human Factors Society ELECTED

Contributions in this section of your Journal are earnestly solicited. They should be typed double-spaced and sent to the Editor three months preceeding the issue for which they are intended.

DEPARTMENT OF THE ARMY

Helmut Sommer has received the Army's Meritorius Civilian Service Award. This second highest award that a civilian employee can receive is the second one for Dr. Sommer. His first came 24 years ago from the Department of Commerce.

Dr. Sommer, Chief Scientist and Associate Technical Director, Harry Diamond Laboratories (HDL) Adelphi, Maryland, was recognized for his outstanding technical management leadership in providing direction to a large number of complex electronic research and development programs. His contributions to proximity fuzing and nuclear radiation effects has improved the Army's capability in many fields of ordnance and electronics.

Dr. Sommer received all his degrees majoring in electrical engineering from Texas A&M University—BS in 1944, MS in 1947 and PhD in 1950. In addition he earned some graduate credits from Massachusetts Institute of Technology during World War II. After completing his academic requirements, he did his thesis research at the National Bureau of Standards in electrical engineering and physics.

Dr. Sommer served as a radar officer in the Signal Corps from 1943 to 1946. He joined the Atomic Physics Section of the National Bureau of Standards in 1949 and transferred to HDL (then the Diamond Ordnance Fuze Laboratory) in 1953. In 1957 he left HDL on a leave of absence to join the staff of the University of Florida as a research professor in its Electronics Laboratory. Dr. Sommer returned to HDL in 1958 and has subsequently served as Chief of the Radio Systems Branch, Chief of the Microwave Branch, and, finally, Chief of the Systems Research Laboratory, where he planned, directed and administered scientific programs involving more than a hundred engineers, technicians and administrative personnel.

Dr. Sommer has authored numerous technical publications, and is a member of several professional societies including the Philosophical Society of Washington, the Washington Academy of Sciences, the Institute of Electronic and Electrical Engineers, and two professional fraternities, Tau Beta Pi and Sigma Xi.

A native of Geislingen, Wurttemberg, Germany, Dr. Sommer came to this country at an early age and attended public schools in Dickinson, Texas. In 1946 Dr. Sommer married Ethel K. Benoist, whom he began dating in college, although they are both from the same town. The Sommers have six children, Richard J., Kathryn T., John R., Stephen A., Michael T., and Michele M., and they live in Bethesda, Maryland.

NAVAL RESEARCH LABORATORY

Lendell E. Steele of the Naval Research Laboratory (NRL) was presented with the Navy Superior Civilian Service Award for outstanding research accomplishments in special ceremonies on December 9, 1976. Rear Admiral R. K. Geiger, Chief of Naval Research, presented the award, second highest honor that can be bestowed on civilian employees by the Navy, and the highest honorary award given by the Chief of Naval Research.

Mr. Steele, Head of the Thermostructural Materials Branch in the Engineering Materials Division, was honored for his outstanding contributions to the understanding of radiation damage to metals. His personal contributions and those under his research leadership resulted in detailed understanding of radiation damage effects and the influence of these on the integrity of nuclear reactor structures, the development of the procedures for reducing such effects and criteria for producing metals resistant to neutron damage for future reactor structures.

The NRL scientist pioneered in the development of design, fabrication and surveillance criteria and standards which have helped to assure the safety and reliability of power reactors—of particular importance today because of the increased use of nuclear reactors for electric power production. Admiral Geiger stressed that the work of Mr. Steele and his co-workers over the past sixteen years has produced a collective scientific and engineering knowledge of major import to nuclear reactor safety.

A native of North Carolina, Mr. Steele began his career at NRL in 1951. Prior to that he had been a chemist at the Department of Agriculture, a scientific aid at the Department of Interior, a physical science aid at the Department of Commerce, and a laboratory assistant at Furman University. Mr. Steele holds an MA in Economics from the American University and a BS in Chemistry from George Washington University. He resides at 7624 Highland Street, Springfield, Virginia, with his wife, Rowena, and two daughters, Pamela and Linda. Two other daughters, Joyce (Mrs. Brian McCartney) and Carol (Mrs. Ismael Gonzalez) currently reside in Ft. Worth, Texas.

OBITUARY

David G. Knapp

David G. Knapp, geophysicist, died February 8, 1977, in Boulder, Colorado following a short illness.

Born in Indianapolis, July 20, 1907, he worked for the National Bureau of Standards in Washington from 1926–28. While attending Butler University he worked for the Indianapolis Power and Light Company, 1928–36. He obtained a B. S. degree and in 1936 returned to Washington for employment as a mathematician in the Coast and Geodetic Survey. This was the beginning of a lifetime affiliation with the science of geomagnetism. He was an internationally known author of many scientific and technical papers dealing with geomagnetism and had represented his office at many national and international scientific assemblies. His principal interests were mathematical modeling of the earth's magnetic field, in particular for the polar areas and for location of the dip poles, and the history of geomagnetism. Most recently he had been working on a new model of the main field using multipoles. A book on the history of geomagnetism, co-authored with the late Sidney Chapman, remains nearly completed. He was a member of the American Geophysical Union, Sigmi Xi-The Scientific Research Society of North America, and the Washington Academy of Sciences. In the American Geophysical Union he served as secretary of the section of terrestrial magnetism and electricity from 1945–50 and as a member of the editorial and publication committee from 1950–58. He served on several committees of the International Association of Geomagnetism and Aeronomy and was currently chairman of a working group on history. In 1971, along with other geophysicists in the National Ocean Survey of NOAA, he was transferred to the Environmental Research Laboratories in Boulder, Colorado. In 1973, again as part of a major transfer of programs, he moved to the U. S.

Geological Survey in Denver. He retired December 31, 1974 but had continued in USGS as a rehired annuitant. He also retained a desk in the NOAA National Geophysical and Solar-Terrestrial Data Center, where he contributed his expertise as an occasional "guest worker."

He is survived by his wife Doris, who resides at 4695 Osage Drive, Boulder, Colorado 80303. He is also survived by two sons, Barry and Allen, and two daughters, Louise and Emily. Barry and Louise reside in Boulder; Allen in Washington, D. C.; and Emily in Redwood City, California.

—K. L. Svendsen
NOAA/NGSDC
Boulder, CO 80302

NOTICE

Annual Meeting—Association of Official Analytical Chemists

Date:	October 17 to 20, 1977
Where:	Marriott Hotel, Twin Bridges, Washington, DC 20001
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Contact:	L. G. Ensminger, Executive Secretary, AOAC, Box 540, Benjamin Franklin Station, Washington, DC 20044

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L'Hôpital's Rule As A Chemist's Tool

Simon W. Strauss

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ABSTRACT

The usefulness of L'Hôpital's rule as a practical alternative method for the evaluation of chemically oriented indeterminate forms is illustrated with examples chosen from chemical kinetics, solid state theory, chemical engineering, and thermodynamics.

Physical chemistry textbooks use 2 general approaches for dealing with those special cases where rate equations become indeterminate. The one most frequently used involves imposing on the original differential equation the same condition that made the integrated rate equation one of indeterminate form. Integration of the modified differential equation yields the desired rate equation (see, for example, Moore (1)). An interesting variation of this procedure is given by Rose (2). The second approach involves the use of series to evaluate the indeterminate forms (see, for example, Glasstone (3)).

An alternative method to the above (not discussed in physical chemistry textbooks) which can be used simply and effectively to evaluate indeterminate rate equations as well as other indeterminate expressions arising in chemistry and elsewhere, involves the application of the so-called L'Hôpital's (also spelled L'Hôspital's) rule. In this connection, it appears befitting to point out that Mellor's Higher Mathematics for Students of Chemistry and Physics, the fourth edition of which was published over 60 years ago, contains a student exercise requiring the use of L'Hôpital's rule to evaluate a second order rate equation of indeterminate form (4). The purpose of the present paper is to illustrate the usefulness of L'Hôpital's rule as a practical alternative method for the evaluation of some indeterminate forms which may be of interest to chemists and chemical engineers as well as to some physicists.

A number of mathematical theorems, usually referred to collectively as L'Hôpital's rule (to be referred to henceforth as L. R.), provide an important technique for finding the limit of a quotient of 2 functions in circumstances such that the limit cannot be found directly by the rule that the limit of a quotient is the quotient of the limits (5,6). For the purpose of the present paper, L. R. may be stated as follows: If the quotient $f(x)/g(x)$ assumes an indeterminate form 0/0 or ∞/∞ when $x = u$, where u may be finite or infinite, then

$$\lim_{x \to u} \frac{f(x)}{g(x)} \qquad (1)$$

will be equal to the first of the following expressions which is not indeterminate provided this expression exists; and if it fails to exist, the limit sought also fails to exist:

$$\lim_{x \to u} \frac{(d/dx)[f(x)]}{(d/dx)[g(x)]}; \quad \lim_{x \to u} \frac{(d^2/dx^2)[f(x)]}{(d^2/dx^2)[g(x)]};$$

$$---; \quad \lim_{x \to u} \frac{(d^n/dx^n)[f(x)]}{(d^n/dx^n)[g(x)]}. \quad (2)$$

In the above notation, $f(x)$ and $g(x)$ are functions of x which tend to zero or infinity as x tends to u. We are now ready to apply L. R. to some chemically oriented indeterminate forms selected from the areas of chemical kinetics, solid state theory, chemical engineering, and thermodynamics.

Second Order Rate Equation (7)

For the reaction represented by the equation

$$\underset{(a-x)}{A} + \underset{(b-x)}{B} \xrightarrow{k} \underset{x}{\text{Products}}, \quad (3)$$

the integrated form of the rate equation may be expressed as

$$\frac{x}{a} = \frac{1 - e^{kt(a-b)}}{1 - \alpha e^{kt(a-b)}}, \quad (4)$$

where a and b are the initial concentrations of the reactants A and B, respectively, $\alpha = a/b$; x is the concentration of the products at time t; and k is the specific rate constant. At $b = a$, the right hand side quotient of equation (4), designated for convenience by m/v (m = numerator; v = denominator) becomes indeterminate, 0/0, and is, therefore, an obvious candidate for application of L. R. We wish to find the limit of m/v as b approach a, that is, $\lim_{b \to a} \frac{m}{v}$

We proceed as follows:

$$\frac{x}{a} = \lim_{b \to a} \frac{m}{v} = \lim_{b \to a} \left[\frac{dm}{db} \Big/ \frac{dv}{db} \right]. \quad (5)$$

Performing and simplifying the indicated differentiation yields

$$\frac{x}{a} = \lim_{b \to a} \frac{b^2kt}{a(1 + bkt)} \quad (6)$$

$$= \frac{akt}{1 + akt}, \quad (7)$$

or,

$$kt = \frac{x}{a(a - x)}, \quad (8)$$

which is the desired equation.

Third Order Rate Equation (8)

For the reaction

$$\underset{(a-x)}{A} + \underset{(b-x)}{B} + \underset{(c-x)}{C} \xrightarrow{k} \underset{x}{\text{Products}}, \quad (9)$$

the specific rate constant is given by the equation

$$kt = \frac{(b - c) \ln\left(\frac{a - x}{a}\right) + (c - a) \ln\left(\frac{b - x}{b}\right) + (a - b) \ln\left(\frac{c - x}{c}\right)}{(a - b)(b - c)(c - a)}$$

$$= \frac{r}{w}, \quad (10)$$

where c is the initial concentration of the reactant C. When $c = b$, the quotient, r/w, becomes indeterminate, 0/0. Applying L. R., gives

$$kt = \lim_{c \to b} \left[\frac{dr}{dc} \Big/ \frac{dw}{dc} \right] \quad (11)$$

$$= \lim_{c \to b} \left[\frac{\dfrac{x(a-b)}{c(c-x)} + \ln \left[\dfrac{a(b-x)}{b(a-x)}\right]}{(a-b)(b-2c+a)} \right] \tag{12}$$

$$= \frac{\dfrac{x(a-b)}{b(b-x)} + \ln \left[\dfrac{a(b-x)}{b(a-x)}\right]}{(a-b)^2} = \frac{y}{z}. \tag{13}$$

Let us now consider equation (13) for the special case where $b = a$. The quotient, y/z, becomes 0/0. Applying L. R. to equation (13),

$$kt = \lim_{b \to a} \left[\frac{dy}{db} \Big/ \frac{dz}{db} \right], \tag{14}$$

which, after differentiation, followed by simplification in a manner such as that discussed by Thomas (9), gives

$$kt = \lim_{b \to a} \left[\frac{x(2b-x)}{2b^2(b-x)^2} \right] \tag{15}$$

$$= \frac{x(2a-x)}{2a^2(a-x)^2}. \tag{16}$$

Equation (16), is, of course, also obtainable by putting $a = b = c$ in the original differential equation and then integrating it.

General Case of A Rate Equation (10)

The integrated rate equation for a reaction of the nth order, all the initial concentrations being the same, is

$$kt = \frac{(a-x)^{(1-n)} - a^{(1-n)}}{n-1} = \frac{q}{s}. \tag{17}$$

At $n = 1$, q/s becomes 0/0. Applying L. R.,

$$kt = \lim_{n \to 1} \left[\frac{dq}{dn} \Big/ \frac{ds}{dn} \right] \tag{18}$$

$$= \lim_{n \to 1} \times [a^{(1-n)} \ln a - (a-x)^{(1-n)} \times \ln(a-x)] \tag{19}$$

$$= \ln \left(\frac{a}{a-x} \right). \tag{20}$$

By letting $x = a/2$ in equation (17), the general equation for the half-life, $t_{1/2}$, is

$$t_{1/2} = \frac{a^{(1-n)}[2^{(n-1)} - 1]}{(n-1)k} = \frac{h}{e}. \tag{21}$$

At $n = 1$, h/e becomes 0/0. Applying L. R.

$$t_{1/2} = \lim_{n \to 1} \left[\frac{dh}{dn} \Big/ \frac{de}{dn} \right] \tag{22}$$

$$= \lim_{n \to 1} \frac{a^{(1-n)} \ln \left[a \left(\dfrac{2}{a} \right)^{2^{(n-1)}} \right]}{k} \tag{23}$$

$$= \frac{\ln 2}{k}, \tag{24}$$

which is also obtainable by putting $x = a/2$ in equation (20).

Consecutive Reactions (11)

The simplest case arises when there are two consecutive stages of the first order, viz.,

$$\begin{matrix} A & \xrightarrow{k_1} & B & \xrightarrow{k_2} & C \\ N_1 & & N_2 & & N_3 \end{matrix}, \tag{25}$$

where the initial concentration of A is N_0; the concentrations of A, B and C, respectively, at time t are N_1, N_2 and N_3; and k_1 and k_2 are the 2 specific rate constants. It is also assumed that at $t = 0$, $N_2 = N_3 = 0$.

The following expressions for N_1, N_2, and N_3 may be readily derived (11):

$$N_1 = N_0 e^{-k_1 t}, \tag{26}$$

$$N_2 = \frac{N_0 k_1 (e^{-k_1 t} - e^{-k_2 t})}{k_2 - k_1}, \tag{27}$$

$$N_3 = \frac{N_0[k_2(1 - e^{-k_1 t}) - k_1(1 - e^{-k_2 t})]}{k_2 - k_1}. \tag{28}$$

If $k_2 = k_1$ (12), the quotients of equations (27) and (28) would become indeterminate, 0/0. Applying L.R. to each of 2 quotients in the manner illustrated in previous examples, we get the following:

$$N_2 = \lim_{k_2 \to k_1} N_0 k_1 t e^{-k_2 t} \tag{29}$$

$$= N_0 k_1 t e^{-k_1 t} \tag{30}$$

$$N_3 = \lim_{k_2 \to k_1} N_0[1 - e^{-k_1 t} - k_1 t e^{-k_2 t}] \tag{31}$$

$$= N_0[1 - (1 + k_1 t)e^{-k_1 t}]. \tag{32}$$

Equation (32) could also have been readily obtained by simple algebraic means using equations (26), (30) plus the fact that $N_0 = N_1 + N_2 + N_3$.

Einstein Specific Heat Equation (13, 14)

This equation may be written as

$$C_v = \frac{3R\left(\frac{h\nu}{2kT}\right)^2}{\left[\sinh\left(\frac{h\nu}{2kT}\right)\right]^2}, \tag{33}$$

where C_v is the molar heat capacity of a solid at constant volume, R is the gas constant, h is Planck's constant, ν is the frequency of vibration of a particle in the lattice, k is Boltzmann's constant, and T is the Kelvin Temperature. At high temperatures (or more correctly as $T \to \infty$), the quotient becomes 0/0. Applying L. R., gives

$$C_v = \lim_{T \to \infty} \frac{3R\left(\frac{h\nu}{kT}\right)}{\sinh\left(\frac{h\nu}{kT}\right)} \tag{34}$$

which is still of the form 0/0 (as $T \to \infty$); hence we can apply L. R. again and get

$$C_v = \lim_{T \to \infty} \frac{3R}{\cosh\left(\frac{h\nu}{kT}\right)} = 3R. \tag{35}$$

An alternative method, using series, for obtaining equation (35) from an exponentially equivalent form of equation (33) is given by Mandl (15).

Example from Chemical Engineering (16)

An equation encountered in absorption, distillation, extraction and leaching is of the form

$$y = \frac{x^{(n+1)} - x}{x^{(n+1)} - 1}. \tag{36}$$

In gas absorption, with systems where Henry's law applies to the gas-liquid equilibrium, y represents the fraction of solute in the inlet gas that is absorbed in a tower of n perfect plates, and x is the ratio of solute-free liquor rate to gas rate, divided by Henry's law constant. When $x = 1$, the quotient in equation (36) becomes 0/0. Applying L. R.,

$$y = \lim_{x \to 1} \frac{(n + 1)x^n - 1}{(n + 1)x^n} \tag{37}$$

$$= \frac{n}{n + 1} \tag{38}$$

which is the desired value for y at $x = 1$ (16).

Example from Thermodynamics (17)

A polytropic process is one for which the pressure-volume relation is given by

$$PV^n = \text{constant}, \tag{39}$$

where P is the pressure; V is the volume; and n is a constant (17). Assuming a perfect gas, the work, W, done by the system is

$$W = \frac{P_1 V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{(n-1/n)}\right]}{n - 1}. \tag{40}$$

where the subscripts 1 and 2 refer to initial and final states. At $n = 1$, the quotient in equation (40) becomes 0/0.

Applying L. R., we obtain, after simplification,

$$W = \lim_{n \to 1} \frac{P_1V_1 \left[\left(\frac{P_2}{P_1} \right)^{(n-1/n)} \ln \left(\frac{P_1}{P_2} \right) \right]}{n^2} \quad (41)$$

$$= P_1V_1 \ln \left(\frac{P_1}{P_2} \right) \quad (42)$$

$$= RT \ln \left(\frac{P_1}{P_2} \right) \quad (43)$$

since for 1 mole of an ideal gas $PV = RT$. Equation (43), the well known expression for the maximum work in an isothermal reversible expansion of an ideal gas, may also be readily obtained by other means (18).

Concluding Remarks

As illustrated with a number of examples in the present paper, L. R. can indeed be used as a chemist's tool. Perhaps some students reading this paper might be sufficiently stimulated to search for applications of L. R. to some other indeterminate forms of interest to the scientist and engineer in general and to the chemist in particular. To those students, the following words of caution might be in order: to preclude the possibility of obtaining absurd results, we must satisfy ourselves that we are indeed dealing with an indeterminate form 0/0 of ∞/∞ before applying L. R. Finally, whereas a limit that can be obtained by L. R. can also be evaluated by elementary methods, the use of L. R. makes the work in general much easier (19).

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A Review of the Pathogens and Parasites of the Biting Midges (Diptera: Ceratopogonidae)

Willis W. Wirth

Systematic Entomology Laboratory, IIBIII, Agr. Res. Serv., USDA, c/o U. S. National Museum, Washington, D. C. 20560

ABSTRACT

A review is presented of all published information on parasites and pathogens of biting midges of the dipterous family Ceratopogonidae. Viruses furnished two records; Rickettsiae 1; Bacteria 6; Fungi 8; Protozoa 23; Nematoda 21; Acarina 18; and Insecta Hymenoptera 4. A bibliography of 90 titles is given. It is believed that mermithid nematode parasites offer some promise in biological control of *Culicoides* disease vectors.

The literature on natural enemies of biting midges is not extensive. Helpful reviews were published by Weiser (1963a, 1975), Jenkins (1964), and Bacon (1970). This review has been prompted by my involvement in 3 related review projects: 1) a compilation of a complete bibliography and a key-word in-context index to the published literature on the Ceratopogonidae (Atchley, Wirth, and Gaskins, 1975); 2) preparation of introductory chapters on ceratopogonid biology for a manual to the genera of the Ceratopogonidae (Wirth, Ratanaworabhan, and Blanton, in preparation); and 3) preparation of a chapter on parasites and pathogens of biting midges for a revision of Jenkins' World Health Organization bulletin (1964). In each of these activities different emphasis has been placed on content and organization of the information to be included, depending on the primary purpose of the review. I am here choosing a format to bring to the attention of workers interested in the control of biting midges a resumé of the known pathogens and parasites offering the most promise in biological control.

For brevity a decision was made, perhaps too arbitrarily, to exclude, or to mention only briefly, references to several groups of parasites of ceratopogonids that probably would have little significance in biological control. These include protozoan and nematode parasites pathogenic to birds and mammals for which ceratopogonids are known to be alternate hosts without suffering known adverse effects from the parasitism. Examples are bluetongue virus and the filarial parasites just mentioned, and *Haemoproteus*, *Hepatocystis*, and *Leucocytozoon* protozoans. Some of these organisms have considerable medical or veterinary literature concerned with disease transmission in vertebrate hosts.

A discussion of predators of Ceratopogonidae would be too long and involved to include here and should be the subject of a separate review. The prey habits of predators tend to be less specific, and preliminary studies of predation tend to include more fortuitous records than studies of parasites and pathogens. Our interest and knowledge of the possibilities of biological control of biting midges are still in such an early stage that a meaningful review cannot be made. Yaseen (1974) searched for natural enemies of West Indian ceratopogonids for nearly a year without finding any parasites or pathogens. The only natural enemies found were adults of a tiger-beetle, *Cicindela suturalis* F., which fed on pupae and adults of *Culicoides phlebotomus* (Williston).

Insect resistance to pesticides and environmental concerns about long-range effects of repeated applications of pesticides have led to emphasis on alternative methods of control. Integrated control, which calls for the timely and frugal application of pesticides while exploiting every possibility for the use of natural enemies and habitat management, offers the maximum promise for relief from damage and annoyance caused by insect problems. A detailed knowledge of the ecology of insect pests and their natural enemies is essential for effective control.

Compared with mosquitoes, lice, fleas, and some other bloodsucking pests of man and domestic animals, research on the biology and natural enemies of biting midges (Ceratopogonidae) has received little emphasis. Because of their small size and difficulty of colonization comparatively little work has been done in determining ceratopogonid vectors of disease organisms of medical and veterinary importance. Lacking a proven basis as disease vectors, the study of ceratopogonids has been further neglected. Our knowledge of natural enemies of biting midges is in an early embryonic stage, compared with what is known, for instance, for mosquitoes.

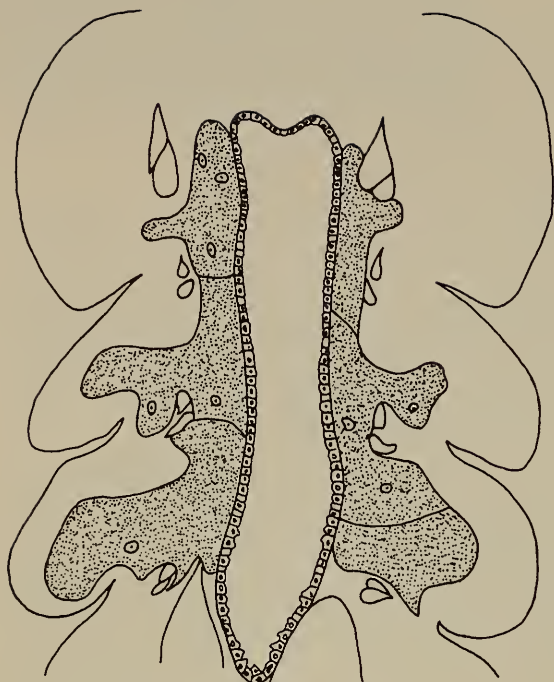
Viruses

Chapman et al. (1968) and Chapman (1973) reported the first pathogenic virus in a biting midge. Over an 11-month period in Louisiana they found nearly 50% of the larvae of *Culicoides arboricola* Root and Hoffman from 3 tree holes infected with an iridescent virus (CuIV). Infection caused death of the larvae. Infected dead larvae placed in several other tree holes eventually produced some infected *Culicoides* larvae.

Clark and O'Grady (1975) collected larvae of *Culicoides cavaticus* Wirth and Jones from tree holes in California that exhibited symptoms of a disease similar to that caused by the "tetragonal virus" reported by Kellen et al. (1963), Clark and Chapman (1969), and Stoltz et al. (1974) in mosquitoes in California and Louisiana. "Infected larvae were easily identified by their sluggish activity, which contrasted sharply with their normally rapid swimming movements. As the disease progressed, the body of the larva stiffened, first in the middle segments and then toward both extremities. Heart pulsations could be detected after the extremities ceased movement. After death, the body remained rigid and straight until post-mortem changes resulted in the dissolution of larval tissues . . . . In the original collection, all of the *Culicoides* larvae eventually died with the symptoms just described. In subsequent collections, the mortality rate ranged from about 70 to 90%". Non-occluded viruslike particles from various tissues of the larvae were observed with the aid of an electron microscope. Apparently normal larvae usually died about 3 days after exposure to water contaminated with the remains of larvae killed by the disease. Attempts to infect *Culex* and *Aedes* mosquito larvae and *Musca domestica* larvae by feeding them infected *Culicoides* tissues were negative.

Rickettsiae

Hertig and Wolbach (1924) found tiny, rickettsia-like cocci, diplococci, and short rods in smears of the bodies of adults of *Culicoides sanguisuga* (Coquillett) from Massachusetts. Nine out of 27 individuals were infected, the rickettsiae occurring free in smears of the abdomen, although greater numbers were seen in lobes of the fat body.



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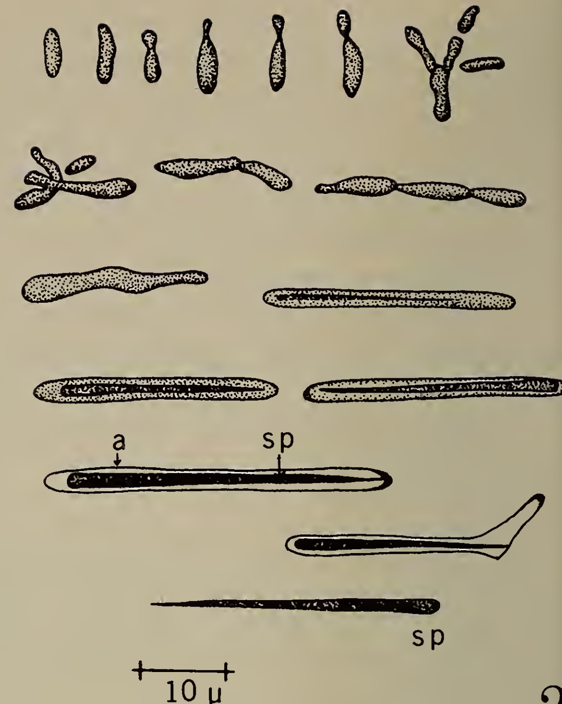

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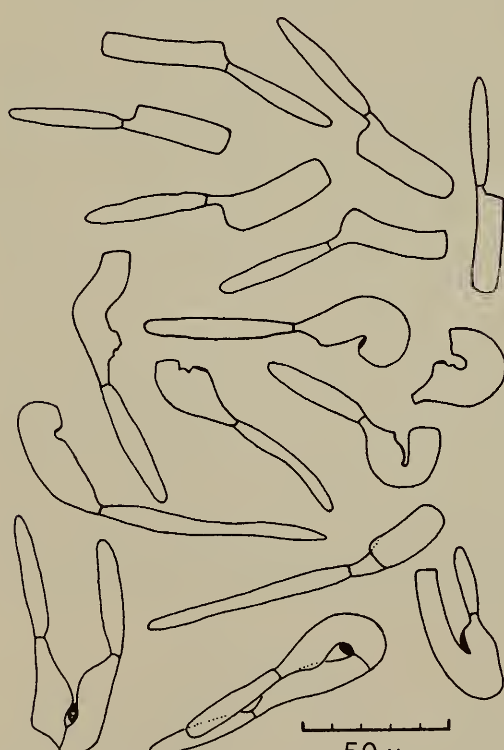

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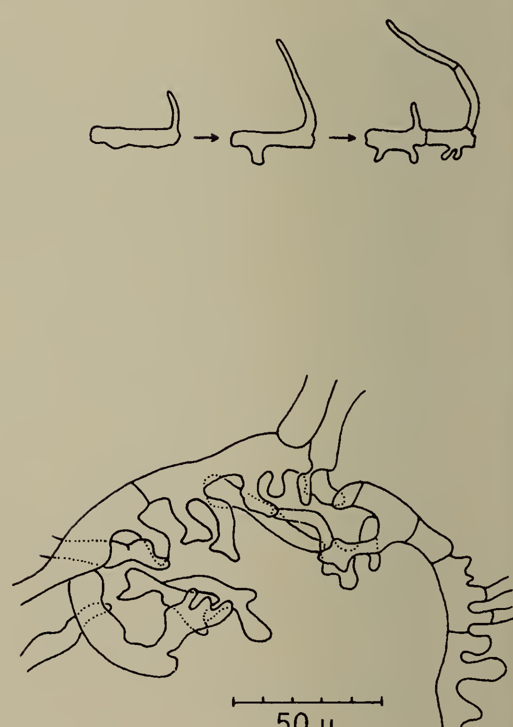

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Fig. 1. Mycetome of bacteria in thorax and anterior abdominal segments of *Dasyhelea* imago (after Buchner, 1930). Fig. 2. Stages in budding cells and spore formation of the fungus *Monosporella unicuspidata* in *Dasyhelea obscura* (after Keilin, 1920); a, ascus; sp, ascospore. Fig. 3. Different aspects of the diaspores of *Carouxella scalaris* in *Dasyhelea lithotelmatica* after their liberation, showing the stout protoconidia and slender conidia (after Manier et al., 1961). Fig. 4. Adherent mycelium of *Rubettella inopinata* in *Dasyhelea lithotelmatica* (after Manier et al., 1961).

Bacteria

Keilin (1921a, 1927) found 2 pairs of masses of bacteria present in the body cavity of the thorax of *Dasyhelea obscura* (Winnertz) in England. These organisms, which he termed "hereditary bacterian symbionts," pass from stage to stage in these masses and appear in the egg stage. Stammer (in Buchner, 1930) reported similar bacteria forming a syncytium in mycetomes in the thorax of *Dasyhelea versicolor* (Winnertz) in Germany (fig. 1). Mayer (1934) observed similar mycetomes in larvae of *Culicoides* species in Germany. Lawson (1951) found bi-refringent, non-fluorescent, minute, motile particles in cells of the fat bodies of *Culicoides nubeculosus* (Meigen) in Britain, that he speculated may be symbionts of the type found by Keilin. Becker (1958) identified as *Pseudomonas* sp. fluorescent bacteria isolated from larvae of *Culicoides salinarius* Kieffer in Scotland. He presumed that these bacteria were also symbiotic.

Fungi

Keilin (1920a, 1921a, 1927) described an Ascomycete fungus, *Monosporella unicuspidata*, from the body cavity of larvae of *Dasyhelea obscura* (Winnertz) in England (fig. 2). Infected larvae could be recognized by their milky appearance. The fungus is pathogenic to the larvae, which die with the body cavity completely filled with the spores of the fungus.

Ciferri (1929) grew cultures of *Grubyella ochoterenai*, a fungus parasite originally collected in Mexico from dead bodies of *Simulium* larvae, in the laboratory in the Dominican Republic on adults of *Culicoides phlebotomus* (Williston). Mayer (1934) reported finding Ascomycete fungi of the group Laboulbeniales on *Forcipomyia* sp. in Germany. According to Steinhaus (1949) these fungi are usually harmless commensals.

Manier et al. (1961) described 2 new Trichomycete fungi from *Dasyhelea lithotelmatica* Strenzke in France: *Rubetella inopinata* (fig. 4) and *Carouxella scalaris* (fig. 3). The first develops in the anterior part of the hind gut and the second in the rectal ampullae of the *Dasyhelea* larvae. Gol'berg (1969) reported an epizootic among ceratopogonid midges in a water reservoir in the filtration fields of a village near Moscow caused by *Entomophthora ovispora* Nowak.

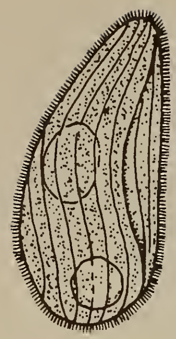
Megahed (1956) found "fungal hyphae" in the lumen of the oesophageal diverticulum of *Culicoides nubeculosus* (Meigen) in laboratory colonies in Britain and speculated that the spores must have been ingested with raisin sap and have developed within the diverticulum. Lewis (1958) found fungal hyphae in the duct of the crop of a dissected female of *Culicoides furens* (Poey) in Jamaica.

Protozoa

Weiser (1963a) stated that while members of every protozoan class parasitize insects, the important pathogens belong to the Gregarina, Coccidia, Microsporidia, and Haplosporidia. Most species found in the intestinal tract are harmless commensals, whereas those living in the gut walls may cause tissue destruction and death of the host.

Ciliata

Ghosh (1925) described a ciliate, *Balantidium knowlesii* (fig. 5), from the coelomic cavity of *Culicoides peregrinus* Kieffer (stage not given) in India. According to Jenkins (1964) this species is a synonym of *Tetrahymena pyriformis* (Ehrenberg). Laird (1960) stated that *Tetrahymena* ciliates are normally free-living but may invade wounded or moribund larvae of mosquitoes, and sometimes even healthy ones. In 1959 Laird reported that *T. pyriformis* is a well-known facultative parasite of various mosquitoes and other aquatic insects. Chapman et al. (1969) reported a ciliate identified as *Tetrahymena* sp. from larvae of *Culicoides* probably *nanus* Root and Hoffman in Louisiana. Sharp (1928) reported unidentified ciliates from the dissected bodies of 3 out of 540



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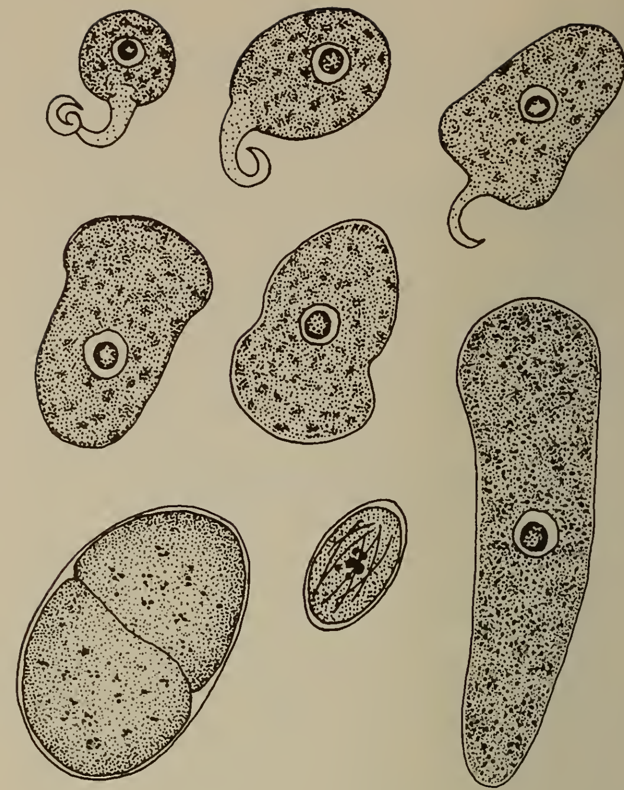

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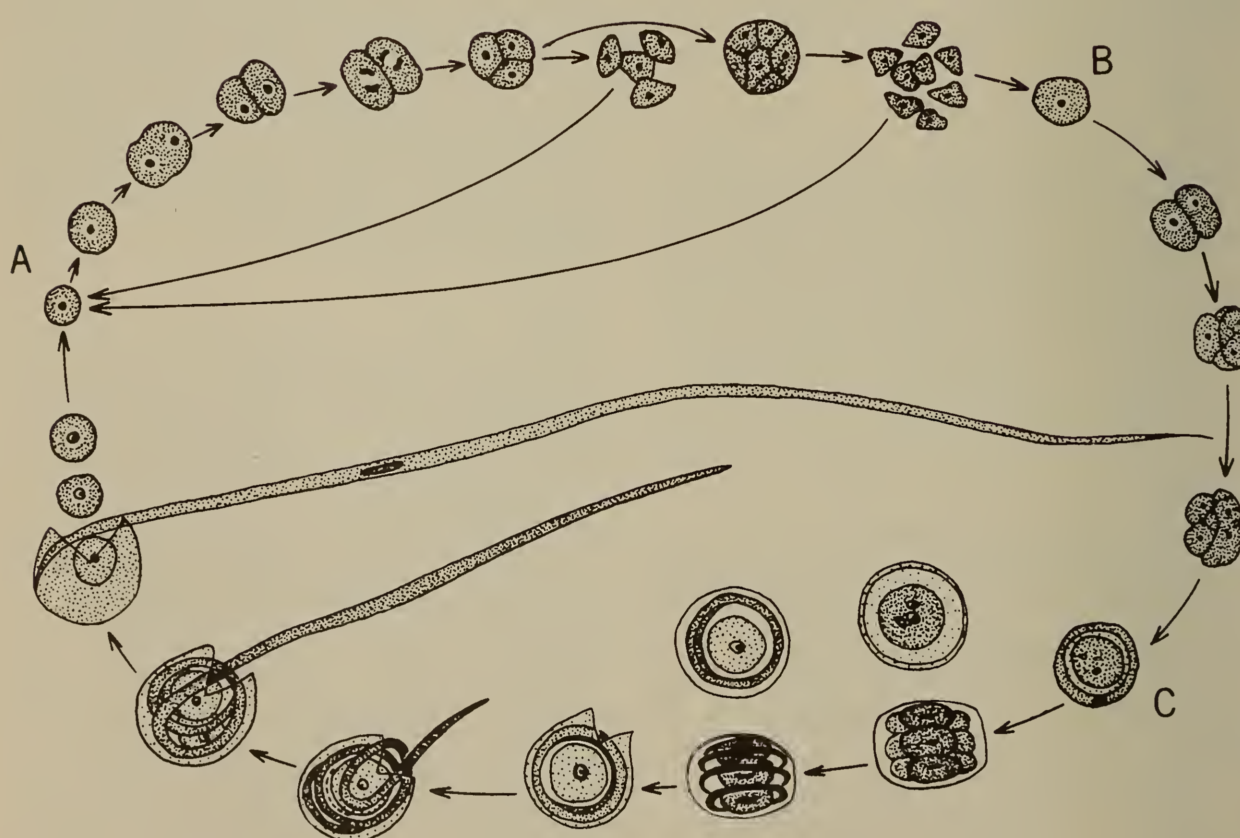

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Fig. 5. *Balantidium knowlesii* from the coelomic cavity of *Culicoides peregrinus* (after Ghosh, 1925). Fig. 6. *Taeniocystis parva*, a gregarine from the larva of *Forcipomyia* sp. (after Foerster, 1938). Fig. 7. *Stylocystis riouxi*, an eugregarine parasite from the larva of *Dasyhelea lithotelmatica* (after Tuzet and Ormières, 1964). Fig. 8. Life cycle of *Helicosporidium parasiticum* from *Dasyhelea obscura*; a, schizogonic multiplication; b, formation of morula; c, spore formation; d, stages in opening of sporocyst, unrolling of spiral filament, and liberation of sporozoite (after Keilin, 1921).

wild-caught females of *Culicoides austeni* Carter, Ingram, and Macfie in the Cameroons.

Becker (1958) reported ciliates identified as *Perezella* sp. (Perezellidae, Astomata) living in the haemocoeles of *Culicoides* larvae in Scotland. Up to 20% of the larvae in various samples were parasitized, and the number of parasites per larva varied from a few until they became closely packed in the haemocoel. *Culicoides salinarius* Kieffer, *odibilis* Austen, and *riethi* Kieffer were parasitized. Becker quoted unpublished observations of Kettle in Scotland of these parasites in a larva of *C. pulicaris* (L.), and of ectoparasitic cysts, presumably also of *Perezella*, occurring frequently near Glasgow on larvae of *C. cubitalis* Edwards and *pallidicornis* Kieffer. Kettle and Lawson (1952, plate 17a) illustrated these "ectoparasites" on the head and neck of a *C. pallidicornis* larva.

Mastigophora

Weiser (1963a) believes that gut flagellates found in the intestinal tract of insects are harmless commensals. Sharp (1928) reported, for example, that flagellates of the leptomonas type were seen on a number of occasions in dissections of females of *Culicoides austeni* Carter, Ingram, and Macfie in the Cameroons. Kremer et al. (1961) observed that a large proportion of the larvae of *Culicoides salinarius* Kieffer had in their digestive tube a small flagellate similar to but smaller than the *Strigomonas* found in *Culex*.

Recently Hommel and Croft (1975) discovered a flagellate which they placed in the genus *Herpetomonas* Kent infecting 2 to 5% of the adults in the laboratory colony of *Culicoides variipennis* (Coquillett) at Pirbright, England. The parasites were always localized in the Malpighian tubules and sometimes in the midgut and hindgut of the adult midges, and occurred in either opisthomastigote or promastigote stages with a long flagellum. In culture on 4N medium the parasites transformed into aflagellar multiplicative stages with a high degree of polymorphism. The forms with long flagella reappeared in culture after 6 to 8 days. The life cycle was not worked out, but the authors believed that probably early stage midge larvae were infected by forms released by the adult midges. This was the first record of a *Herpetomonas* in the family Ceratopogonidae.

Gregarinida

According to Weiser (1963b) the gregarines parasitic in insects fall in two main classes: (1) Eugregarina, most of which are harmless gut-inhabiting commensals, rarely invading the epithelial tissues, and have lost the schizogonous part of their life cycle. (2) Neogregarina (or Schizogregarina) which invade and undergo schizogony in the gut wall or other tissues and often cause death or serious harm to their host. Tuzet and Rioux (1965) reviewed the classification and life cycles of the gregarines of Ceratopogonidae and other biting Nematocera including the species discussed below.

Schizocystis gregarinoides Léger (1900) is a neogregarine parasite in the gut wall of *Ceratopogon* sp. (Léger, 1900) and *Bezzia solstitialis* (Winnertz) (Léger, 1906) in Europe, parasitizing up to 50% of the larvae sampled and causing the death of the host during metamorphosis. On the other hand the eugregarine *Taeniocystis mira* which Léger (1906) described from *B. solstitialis* in France is less common, infecting up to 20% of the larvae observed, with only 1 to 4 parasites in each larva, and causing little pathological damage to its host. Foerster (1938) described a second *Taeniocystis* species, *T. parva* (fig. 6), from larvae of *Forcipomyia* sp. in Germany.

Keilin (1920b, 1927) described an eugregarine, *Allantocystis dasyhelei*, from larvae of *Dasyhelea obscura* (Winnertz), which lives in decomposed sap in wounds of trees in England. These parasites were rare, and the hosts were never heavily infected; all stages of the gregarine live in the midgut of the insect larva between the intestinal epithelium and the peritrophic tube. A fourth eugregarine ceratopogonid parasite, *Stylocystis riouxi* (fig. 7), was described by Tuzet and Ormières (1964) from larvae of *Dasyhelea lithotelmatica* Strenzke in France.

Microsporidia

According to Weiser (1963a) the Microsporidia are the commonest parasites of medically important insects. Infected hosts are not easily detected unless their bodies are transparent enough to distinguish the opaque-white tissues packed with masses of spores. Microsporidia are pathogenic to some insects while having little pathogenicity to others, having reached a suitable equilibrium with their host.

Léger and Hesse (1922) described 2 microsporidians from the fat bodies of the larvae of *Ceratopogon* sp. in France: *Spironema octospora* and *Toxonema vibrio*. According to Jírovec (1937) and Weiser (1963b) the correct names for these parasites are now *Spiroglugea octospora* (Léger and Hesse) and *Toxoglugea vibrio* (Léger and Hesse). Keilin (1927) also mentioned a parasite which he stated was probably a *Glugea* sp., invading the fat body and salivary glands of *Dasyhelea* larvae in England.

Weiser (1957, 1961, 1963b) described *Nosema sphaeromiadis* from a larva of *Sphaeromias* sp. in Czechoslovakia. The parasites were found in the fat body of the larva. Chapman et al. (1967, 1968, 1969) reported 2 species of *Plistophora* (also nosematids) from at least 2 species of *Culicoides* in Louisiana. One species was observed in *Culicoides* larvae from a shaded woodland pool. A second species in larvae of *Culicoides nanus* Root and Hoffman from tree holes caused death just before pupation. In 1969 *Plistophora* sp. was found in *Culicoides arboricola* Root and Hoffman. Chapman (1973) later reported another parasite of *C. nanus*, an unnamed new species of *Nosema*, from another tree hole at his laboratory. He stated that the levels of infection in these field populations were always less than 1% and that attempts to transmit these parasites to mosquitoes were unsuccessful.

Helicosporidia

Some workers consider this group is closely related to the Microsporidia, but with a peculiar sporogony in which the sporoblast (fig. 8) divides into 4 cells included in a spherical spore. Three of these cells develop into sporozoites, but the fourth changes into a long nucleated filament which apparently functions in opening the spore like an uncoiling spring. The only named species is *Helicosporidium parasiticum* Keilin (1921a), described from larvae of *Dasyhelea obscura* (Winnertz) in England. Later this parasite was reported from a wide range of insect hosts in Europe and North and South America (Weiser, 1970; Kellen and Lindegren, 1973). Weiser considered *Helicosporidium* more likely to be a primitive Ascomycete fungus related to the Nematosporoideae of the Saccharomycetaeae, but Lindegren and Hoffman (1976) suggested that the spore structure showed more affinity with the Protozoa than with the Ascomycete fungi. Most recently Fukuda et al. (1976) were of the opinion that the *Helicosporidium* infecting beetles and mosquitoes were 2 distinct species differing from *H. parasiticum*. They indicated that these parasites showed considerable promise as biological control agents against mosquitoes, but that this is dependent upon further testing for safety to mammals and other non-target organisms.

Haemosporidia

Several Haemosporidia are found in ceratopogonid adults but will only be mentioned briefly here because of their minor pathogenicity to the insect hosts. Their primary interest as parasites concerns their pathogenicity to their vertebrate hosts. Fallis and Bennett (1961) and Bennett et al. (1965) have reviewed this group, which includes such genera as *Parahaemoproteus* which undergoes part of its life cycle in various birds and part in *Culicoides* midges; *Akiba caulleryi* (Mathis and Léger), a pathogenic parasite of poultry in Japan transmitted by *Culicoides arakawai* (Arakawa); and *Hepatocystis kochi* (Laveran), a malaria parasite of *Cercopithecus* monkeys in Kenya transmitted by *Culicoides adersi* Ingram and Macfie.

Nematodes

The nematode parasites of biting midges offering the most promise in biological control belong in the superfamily Mermithoidea, family Mermithidae (Nickle, 1972, 1973). However, mention should be made of several filarial parasites of vertebrates that use Ceratopogonidae as their alternate hosts.

Filarioidea

Many important mosquito-borne filarial parasites of man and domestic animals are well known, for example *Wuchereria bancrofti* (Cobbold) causing elephantiasis in man over much of the tropics, and *Dirofilaria immitis* (Leidy) causing heatworm of dogs and cats. *Onchocerca volvulus* (Leuckart), causing blindness in man in Africa and Central America, is transmitted by Simuliidae. It has been shown that *Dirofilaria* infections may produce heavy mortalities in *Aedes aegypti* (Linnaeus) vectors and that *Simulium* mortality increases with heavy infections of *O. volvulus*. It could also be expected that ceratopogonids, being much smaller insects than mosquitoes or blackflies, would suffer heavy mortality from filarial parasitism. Schacher (1973) gave a comprehensive review of filarial life-cycle patterns and a synopsis of life cycles including insect vectors.

Acanthocheilonema perstans Manson, a non-pathogenic parasite of man in Africa, is transmitted by several *Culicoides* species, notably *C. austeni* Carter, Ingram, and Macfie, and *C. inornatipennis* Carter, Ingram, and Macfie (Sharp, 1928; Hopkins and Nicholas, 1952; Duke, 1954, 1956). Another human filaria in Africa, *Dipetalonema streptocerca* Macfie and Corson, is transmitted by *Culicoides grahamii* Austen (Henrard and Peel, 1949; Duke, 1954). A non-pathogenic human filaria, *Mansonella ozzardi* Manson, was found to be transmitted by *Culicoides furens* (Poey) by Buckley (1934) in the West Indies, and Romaña and Wygodzinsky (1950) infected *C. paraensis* (Goeldi) with this parasite in Argentina.

Filarias of the genus *Onchocerca* are transmitted by *Culicoides* species as well as by blackflies. Steward (1933) infected *C. obsoletus* (Meigen) and *C. nubeculosus* (Meigen) with *Onchocerca reticulata* Diesing, the filaria that causes fistulous withers in horses in Europe and North America.

Bergner and Jachowski (1968) traced the development of *Macacanema formosana* Schad and Anderson, a filarial parasite of Taiwan monkeys, in *Culicoides amamiensis* Tokunaga in Taiwan. Robinson (1961) reported early development of microfilaria in *Culicoides crepuscularis* Malloch that had fed on an infected starling, and in 1971 found that *C. crepuscularis* was the vector of *Chandlerella quiscali* (von Linstow), a filarial parasite of grackles. *Forcipomyia* (*Lasiohelea*) *velox* (Winnertz) was found by Desportes (1941, 1942) to transmit a filarial worm *Icosiella neglecta* Diesing, in frogs in France.

Mermithoidea

According to reviews by Welch (1963), Bacon (1970), and Nickle (1972, 1973) most of the mermithoid parasites of Ceratopogonidae fall in the family Mermithidae. In this family only the larval stages of the worm are found in the body of the insect host. In a typical life cycle of Mermithidae the second stage juvenile nematode, armed with an odontostyle, penetrates the host cuticle and enters the haemocoel. The mermithid feeds on the haemolymph, grows, molts through a number of larval stages, and when approaching maturity, exits through the host cuticle. Mermithids usually select an early instar larva to parasitize;

those that parasitize aquatic insects may be host specific or have a wide range of related host species.

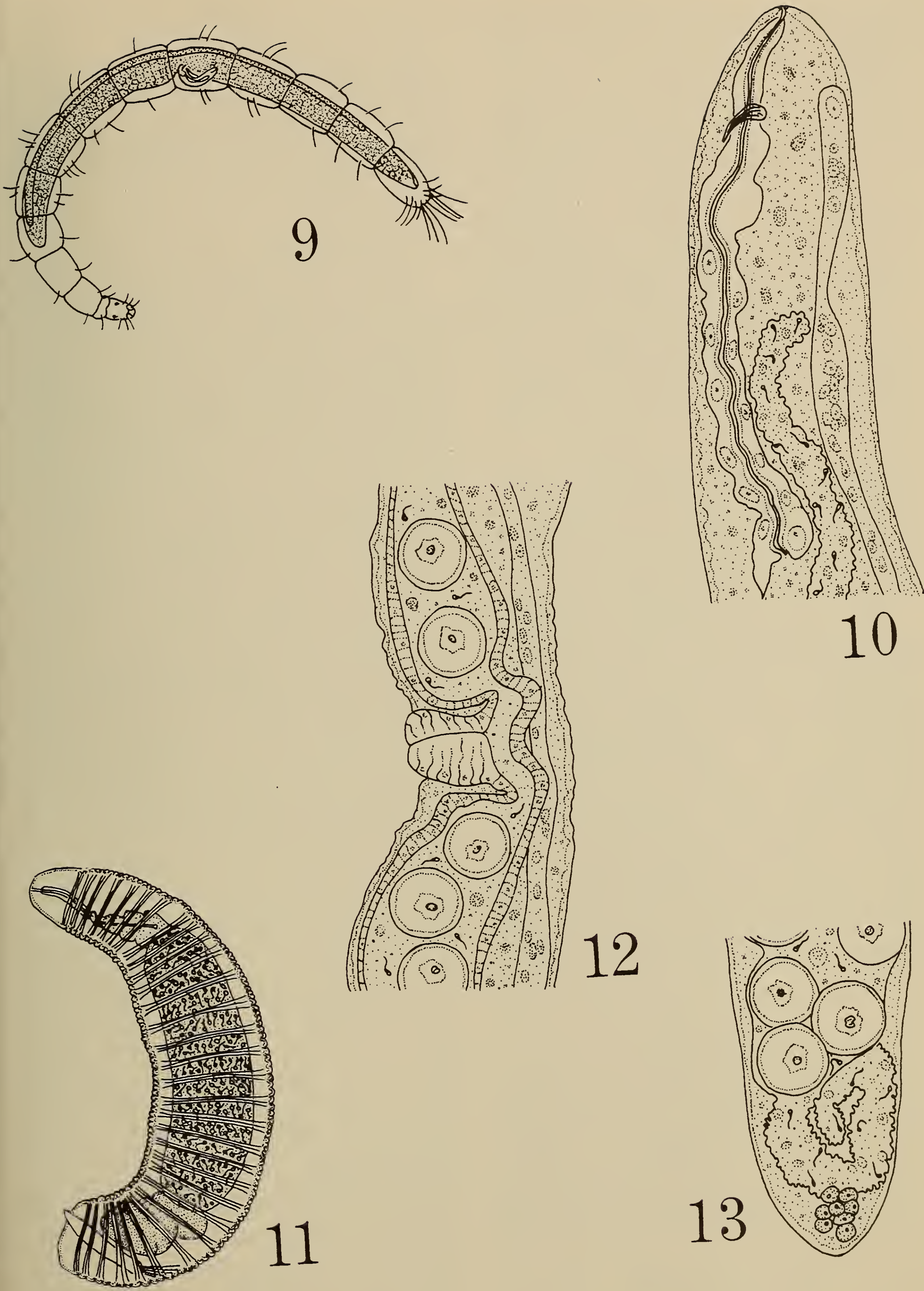
There are 2 types of life cycles in aquatic mermithids. In the first, illustrated by the mosquito parasite, *Romanomermis culicivorax* Ross and Smith, the mermithid eggs are laid in the bottom of a mosquito pool. After hatching the mermithid larva penetrates an early instar mosquito larva, often migrating to the thorax, grows quickly, and emerges from the fourth instar mosquito larva which is killed before pupation. Within 2 or 3 weeks the nematode molts, mates, and lays up to 3000 eggs in the bottom of the pool. This type of mermithid life cycle offers great promise in biological control, and the laboratory culture and release of mermithid eggs is now being undertaken on a large scale over the world. The *Romanomermis* parasite of *Culicoides nanus* Root and Hoffman reported by Chapman et al. (1968) and Chapman (1973) has this type of life cycle (Chapman, pers. com.).

In the second type of life cycle, illustrated by *Perutilimermis culicis* (Stiles) from the saltmarsh mosquito, the mermithid eggs are also laid in the bottom of a mosquito pool. The mermithid larva hatches and enters an early instar mosquito larva, remaining in the head of thorax and not growing at this time. When the mosquito pupates, the mermithid moves to the abdomen but does not enlarge until the mosquito reaches the adult stage and after it has had a blood meal. The mermithid grows rapidly and sterilizes the mosquito, then leaves the host, killing it in the process, while still a larva. The mermithid then enters the pond, molts, mates, and lays thousands of eggs to complete the cycle. Probably most mermithid parasites of aquatic ceratopogonids will have this type of life cycle, although none has yet been worked out in biting midges.

Most of the records of mermithid parasitism in ceratopogonids have to do with the formation of intersexes. In chironomids, which have been investigated in detail, Wülker (1961) found that both sexes were equally parasitized by mermithids and that intersexes had the same cytological sex chromosomes as the sex indicated by their external genitalia. The physiological nature of intersex formation remains poorly understood and urgently needs investigation. Apparently parasite damage to the hormonal system is the most important factor in intersex formation, and anatomic damage and metabolic disturbance are secondary.

In the family Tetradonematidae the adult stages of the worm are also found in the body cavity of the insect host (figs. 9–13). In *Aproctonema chapmani* Nickle (1969), described from *Culicoides arboricola* Root and Hoffman from Louisiana, the nematode passes through its larval stages in the host larvae, which breed in water-filled tree holes. Late instar *Culicoides* larvae may have 1 or more male and female adult worms nearly filling their body cavity. After mating the male nematode dies, and the female, filled with eggs, exits from the midge larva, causing its death. The nematode eggs are laid in the tree hole, and after hatching the infective nematode larvae parasitize other sand fly larvae.

Rubzov (1971, 1972) described a very unusual mermithid from larvae of *Culicoides nubeculosus* (Meigen) and *C. stigma* (Meigen) in Siberian U.S.S.R. as *Heleidomermis vivipara*. Apparently after the adults mate the eggs of this parasite develop within the female worm which remains within the host larva, and the hatched mermithid larvae escape directly from the dead *Culicoides* into the habitat. Further comment on the life cycle must await translation of the original reports in Russian. Additional study of this mermithid is very badly needed to determine its potential usefulness in biological control of *Culicoides variipennis* (Coquillett), the vector of the virus bluetongue disease of sheep and cattle in North America. These *Culicoides* are all closely related, falling within the subgenus *Monoculicoides*, and *C. variipennis* is likely to be susceptible to infection with this nematode. Chemical control of *C. variipennis* associated with



Figs. 9–13. *Aproctonema chapmani* from *Culicoides arboricola*: 9, parasitized *Culicoides* larva containing a large female and small male nematode; 10, female nematode, anterior end; 11, male nematode; 12, female nematode, vulval area; 13, female nematode, posterior end (from Nickle, 1969).

livestock has been impossible because the larvae usually breed in water-filled hoofprints and the margins of ponds or watering places contaminated with feces of the animals. Because the animals use this water for drinking, larvicides pose a toxicity problem, and some form of management or biological control is urgently needed. Control of the disease is presently based on expensive and inconvenient immunization measures.

In 1974 Rubzov described 4 additional new mermithid species from ceratopogonid larvae in the USSR: *Agamomermis gluchovae*, *Gastromermis bezzii*, *Spiculimermis mirzajevae*, and *Heleidomermis ovipara*. In contrast to *H. vivipara*, the female worm of *H. ovipara*, which develops in older instars of the *Culicoides* host larvae, is oviparous. In some populations 60% of the host larvae are infected with *H. ovipara*.

Except for the species mentioned above, very few mermithid parasites of ceratopogonids have been identified to genus, to say nothing of species. It should be noted that *Agamomermis* is an eclectic genus serving as a repository for species described from immature stages, since the generic classification is dependent on characters of the adult worm. Rubzov (1967) described *Agamomermis heleis* from an adult *Culicoides pulicaris* (L.) in the Kazakhstan SSR. Callot (1959) described an intersex adult of *Culicoides albicans* (Winnertz) in France caused by parasitism by an *Agamomermis* sp. Sen and Das Gupta (1964) reported an intersex of *Culicoides alatus* Sen and Das Gupta in India caused by *Mermis* sp., and Das Gupta (1964) reported a *Mermis* sp. causing an intersex in *Atrichopogon* sp. Parasitism of ceratopogonid adults by undetermined mermithids has been reported also by Kieffer (1914) in *Forcipomyia*, by Keilin (1921a) in *Dasyhelea*, by Whitsel (1965) and Glukhova (1967) in *Leptoconops*, and by Buckley (1938), Beck (1958), Smith (1966), Smith and Perry (1967), Glukhova (1967), Chapman et al. (1968), Boorman and Goddard (1970), Mirzaeva (1971), and Service (1974) in *Culicoides*.

Acarina

In view of their conspicuous pink or reddish color and their common occurrence on adult ceratopogonids, it is surprising that so few published records exist of the association of mites with biting midges.

Trombidiiformes

Becker (1958) reported larval trombidiid mites, which were described by Vercammen-Grandjean (1957) as *Evansiella culicoides*, parasitizing adults of 4 species of *Culicoides* in Scotland. He also found larvae of another species identified as *Allothrombium* on the abdomen of a female *Culicoides heliophilus* Edwards. According to Vercammen-Grandjean and Feider (1973), *Evansiella* Vercammen-Grandjean is a synonym of *Centrotrombidium* Kramer and the correct name of the *Culicoides* parasite is *Centrotrombidium culicoides* (V.-G.). Vercammen-Grandjean and Cochrane (1974) described 3 new species of trombidiiform mites parasitizing adults of 10 *Culicoides* species in New York: *Atractothrombium dictyostracum*, *Centrotrombidium dichotomicoxala*, and *Feiderium culicoidium*. Whitsel and Schoeppner (1967) reported another trombidiid mite belonging to the genus *Valgothrombium* parasitizing a male of *Dasyhelea mutabilis* (Coquillett) in California, and quoted another report of this genus on a species of *Culicoides*. These authors quote correspondence with I. M. Newell to the effect that the mites frequent moist situations where they crawl over the substrate in search of prey. Presumably the mites locate the ceratopogonid pupae and attach themselves to the adult as soon as it emerges from the pupa. Mites have also been recorded parasitizing 4 species of "*Ceratopogon*" in the Sunda Islands by Salm (1914), *Culicoides austeni* Carter, Ingram and Macfie in Africa by Sharp (1928), a species of *Dasyhelea* in Argentina by Cavalieri (1968), and *Leptoconops kerteszi* Kieffer in California by Foulk (1969).

In her account of the biology of *Forcipomyia inornatipennis* (Austen) in

Ghana, Kaufmann (1974) described attacks by mites on pupae of the ceratopogonid. She stated, "The ever-present red mites do not normally attack moving prey but do so when movement ceases." Pupae attacked by mites frequently twisted themselves out of their larval exuviae fastened to the substrate and in so doing lost their fastening, and the adults were unable to emerge.

Parasitiformes

Grogan and Navai (1975) reported adult mites of the genus *Amblyseius* (family Phytoseiidae) attached to females of *Culicoides schultzei* (Enderlein) from Nepal. Grogan (1977) recorded a second adult parasitiform mite, *Macrocheles insignitus* Berlese (family Macrochelidae) parasitizing an adult female of *Nilobezzia schwarzii* (Coquillett) in Maryland.

Hydracarina

Smith and Oliver (1976) reviewed the parasitic associations of water mites with imaginal aquatic insects, and summarized the known records of Hydracarina from ceratopogonids. The typical life history pattern is as follows: The adult female mite deposits her eggs on the substrate in the aquatic habitat. Within several days the active hexapod larva hatches and seeks a suitable insect host on the surface film, in the water, or on the substrate. In any case the mite larva attaches to the adult insect at the water surface or when it emerges from the pupa at ecdysis. The mite engorges on haemolymph from the host and remains attached until the host returns to the water. With short-lived dipterous hosts, the engorged mite larva then detaches from the host, re-enters the water and seeks a place to attach its chelicerae, form a nymphochrysalis, and emerge as an active octopod nymph closely resembling the adult mite. After a variable period of maturation the nymph attaches its chelicerae to the substrate, forms an imagochrysalis and transforms to a sexually mature adult. After mating the male mites soon die but the females go on to oviposition, completing the cycle.

Munchberg (1934) reported *Hydrodroma descipiens* (Müller) parasitizing *Mallochohelea inermis* (Kieffer), apparently the first record of a water mite on ceratopogonids. Grogan and Navai (1975) reported larval aquatic mites of the genus *Tyrellia* (family Limnesiidae) parasitizing species of *Atrichopogon*, *Bezzia*, *Culicoides*, and *Dasyhelea* in Maryland. Smith and Oliver (1976) reported larvae of limnesiid mites, probably of a species of *Tyrellia*, parasitizing *Dasyhelea* in Canada. The same authors reported larval mites of the genus *Arrenurus* (family Arrenuridae) on adults of *Bezzia* and *Sphaeromias* in Canada.

Insects

Only 4 species of insects parasitic on ceratopogonids have been recorded, all in 2 closely related families of parasitic Hymenoptera, and all parasitic on the immature stages of the terrestrial and semi-aquatic genus *Forcipomyia*:

Family Diapriidae: *Entomacis longii* (Ashmead) on *F. wheeleri* (Long) in Texas (Long, 1902), and *E. californica* (Ashmead) on *Forcipomyia* sp. in Washington (Bedard, 1938).

Family Encyrtidae: *Forcipestricis gazeaui* Burks on *F. picea* (Winnertz) in Maryland (Burks, 1968; Wirth, 1975), and *F. portoricensis* Gordh on *F. fuliginosa* (Meigen) in Puerto Rico (Gordh, 1975). Apparently these parasites develop in the larvae of *Forcipomyia* and emerge from the larva or pupa, killing the host.

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Wheel Load Distribution on Steel Bridge Planks

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ABSTRACT

The evaluation of concentrated (wheel) load effects on a continuous orthotropic plate supported on flexible supports is predicted by plate theory. In conjunction with experimental tests, the results are applied in the development of a proposed design criteria.

Introduction

During the past several years many counties in the D. C. area were subjected to severe flood damage. These floods caused many bridge structures to be washed out, subsequently creating a need for the construction of bridges. In many instances, the county highway people did not want temporary structures. They desired permanent structures, which would be inexpensive and easily and quickly erected by their personnel. Such criteria can be met by using steel I-girders in conjunction with steel bridge planking, as shown in Fig. 1. In using such planking the designer is faced with a major design problem; that is, the determination of the load distribution factor for proper design of the longitudinal girders. It is, therefore, the intention of this paper to present a design recommendation for such a factor by means of analytical and experimental studies.

Present Criteria

At present the AASHO Specification (1) does not identify the load distribution factor for steel planking. In Section 1.3.1 of the Specification, reference is made to a ''Steel Grid'' floor and states that for two or more traffic lanes and the deck thickness $t < 4.0$ inches, the distribution factor is S/4.0. This specification would probably be the most relevant; however, a ''Steel Grid'' does not resemble the planking and may not give the same distribution factor (S/4.0) as will be seen.

Analytical Studies

General

A bridge plank deck, as shown in Fig. 1, with typical details given in Fig. 2, when interacting with longitudinal flexible girders, can be considered an orthotropic deck. The interaction of an orthotropic deck with longitudinal girders has been studied by Heins and Perry (3). However, in their study, the main girders were positioned transverse to the direction of traffic. The computer program used in this study (3) can, however, be readily applied in establishing the behavior of bridge planking and longitudinal girders.

The analytical model is shown in Fig. 3, with the planking spanning in the strong direction between the girders. The model will have two traffic lanes, span lengths L = 10′, 20′, 30′, 40′, and 50′, and girder spacing between 20″ and 40″, as recommended by a manufacturer of planking (2).

The selection of the girder stiffness was obtained by first evaluating the induced moment on one girder due to a set of truck wheels, and evaluating the section modulus. Also examined was the limiting deflection (L/800) induced by a set of wheels and determining the required stiffness. This preliminary study resulted in the girder sizes given in Table 1. Also included in this table are the girder spacings that were used as a function of the bridge plank gage.

Bridge Plank Properties

1. *Primary Stiffness D_y*

The primary moment of inertia stiffness I_y of a single cell, as shown in Fig. 4, is computed as a function of gage thickness t and equals $I_y = 2.725$ t. The inertia per unit of length for the complete deck shown in Fig. 2 is $I_Y = 1.04$ t/inch. The stiffness is, therefore, equal to $D_y = EI = E \times 1.04t$, where $E = 29 \times 10^3$ ksi.

2. *Minor Stiffness D_x*

The minor moment inertia I_x was evaluated considering two methods. The first was to consider only a single plate of thickness t, which gives $I_x = t^3/12(1 - \mu^2)$. If one considers the corrugation to be sinusoidal, the stiffness $I_x = .67t^3/12(1 - \mu^2)$, as determined by expressions given by Timoshenko (4). The minimum value of I_x will be used in this study, thus the required $D_x = Et^3/12(1 - \mu^2)$.

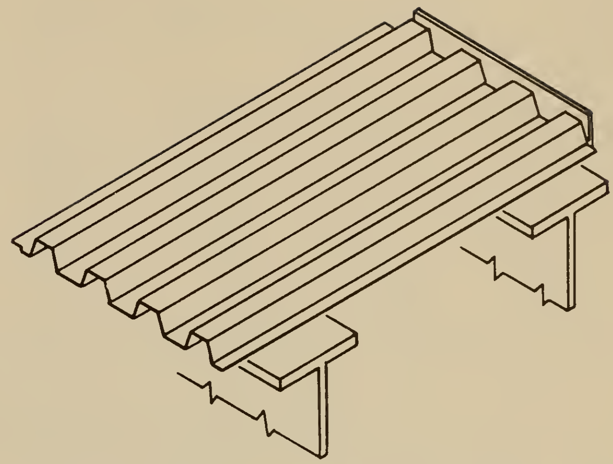


Fig. 1. Bridge planking construction.

3. *Torsional Stiffness H*

The torsional stiffness of the planking can also be estimated by two methods. The first is to assume the stiffness equals the minor stiffness D_x or to use the equation given by Timoshenko (4), which gives $H = E(1.5)t^3/12(1 - \mu^2)$. The minimum value of $H = D_x$ will be used in this study.

4. *Final Stiffness*

The resulting bridge plank stiffnesses for various gages are given in Table 2. The parameter α and β, which equal $\alpha = H/\sqrt{D_xD_y}$, $\beta = H/D_y$, are tabulated values required for the computer input.

Girder Moments

Using the orthotropic computer program (3), the behavior of the bridge system consisting of the various girder spacings, planking stiffness, and span lengths subjected to two AASHO trucks (1) was determined. The resulting maxi-

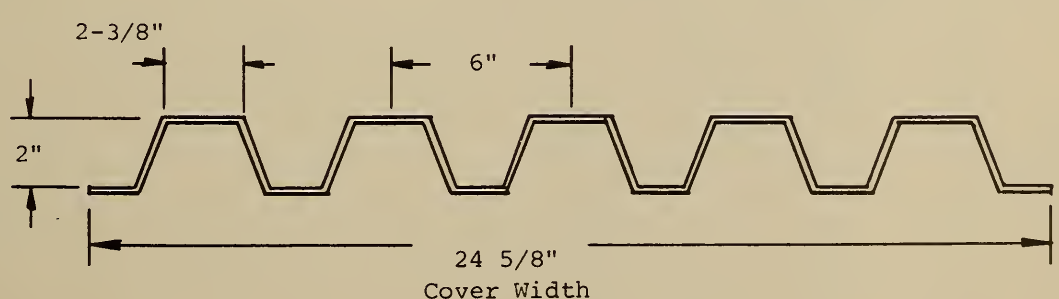


Fig. 2. Bridge plank section.

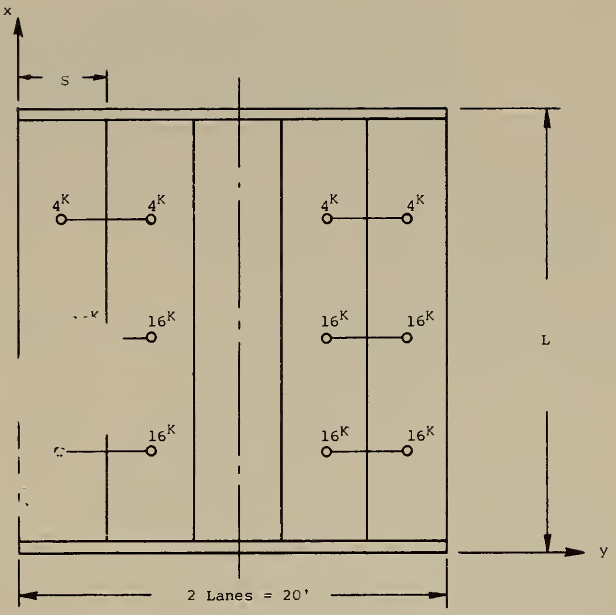


Fig. 3. Bridge loading arrangement.

ment induced girder moments (M) were then compared to the girder moment induced in an isolated girder (M_{SG}) subjected to a single set of truck wheels. The ratio of M/M_{SG} to girder spacing were then plotted, as shown in Fig. 5.

Distribution Factor

The plot of data shown in Fig. 5 actually represents the distribution factor as used in the AASHO Specification (1). The AASHO Specifications do not give a distribution factor for planking; however, a D.F. for grid flooring is given as S/4.0. Evaluating the D.F. for the plot of data given in Fig. 5 is D.F. = S/5.0, which is not as restrictive as S/4.0.

Table 1.—Bridge parameters.

	Gage—Planking			
Length	7 Gage Girder Spacing S (in.)	10 Gage Girder Spacing S (in.)	12 Gage Girder Spacing S (in.)	Girder Size
10′	34	29	26	W12 × 22
20′	37	32	29	W16 × 40
30′	39	34	31	W18 × 85
40′	43	38	35	W21 × 127
50′	44	39	36	W24 × 180

Experiments

As described in the previous section on "Bridge Plant Properties," several values for the stiffnesses can be computed. In order to obtain some guidance relative to the proper stiffness values, a series of plate stiffness tests were conducted.

The test specimens were cut from typical planking samples of seven and twelve gages. Three specimens of each gage were tested in order to determine the respective rigidities D_x, D_y, and H. The test specimens are shown in Figs. 6 and 7 for each test configuration. Similar tests on ribbed plates have previously been described by Heins and Hails (5) (6).

Primary Stiffness D_y

As shown in Fig. 6(a) and 7(a), the corrugation is positioned longitudinally and loaded such that primary beam bending moments are developed. In the pure moment region a series of deflectometers spaced at 6″ were positioned beneath the specimen. Deflections were recorded for each increment of loading. The resulting plate stiffness can then be readily determined by applying the general difference equation:

$$\frac{M}{EI} = y'' = (y_{n-1} - 2y_n + y_{n-1})/\lambda^2 \quad (1)$$

where

λ = Longitudinal spacing between deflection points
n = Deflection point

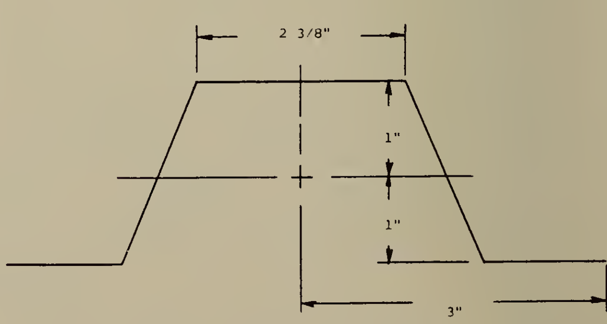


Fig. 4. Typical plank cell.

M = Induced moment
EI = Plate stiffness

For the plate model shown in Fig. 6(a), $M = P \times 24$, $\lambda = 6''$, Width = 24″, thus;

$$D_y = EI/Width = \frac{24P \times 36}{(y_{n-1} - 2y_n + y_{n+1})24}$$

$$D_y = EI/Width = \frac{36P}{(y_{n-1} - 2y_n + y_{n+1})} \quad (2)$$

For each increment of load P up to P_{max} = 7000# (7 gage) and P_{max} = 3000# (12 gage), the y deflections were determined and the subsequent D_y stiffness determined as listed in Table 3 for the 7 and 12 gage specimens.

Table 2.—Bridge plank stiffness.

	Gage		
Stiffness	7 Gage	10 Gage	12 Gage
D_x	15.58	6.68	3.08
D_y	5100.	4070.	3162.
H	15.58	6.68	3.08
α	.055	.0405	.031
β	.0031	.0016	.00097

Secondary Stiffness D_x

Shown in Figs. 6(b) and 7(b), the corrugations are positioned transverse to the supports. This type of arrangement provides minimal stiffness and thus only the dead load response was measured. An equation similar to equation (1) was

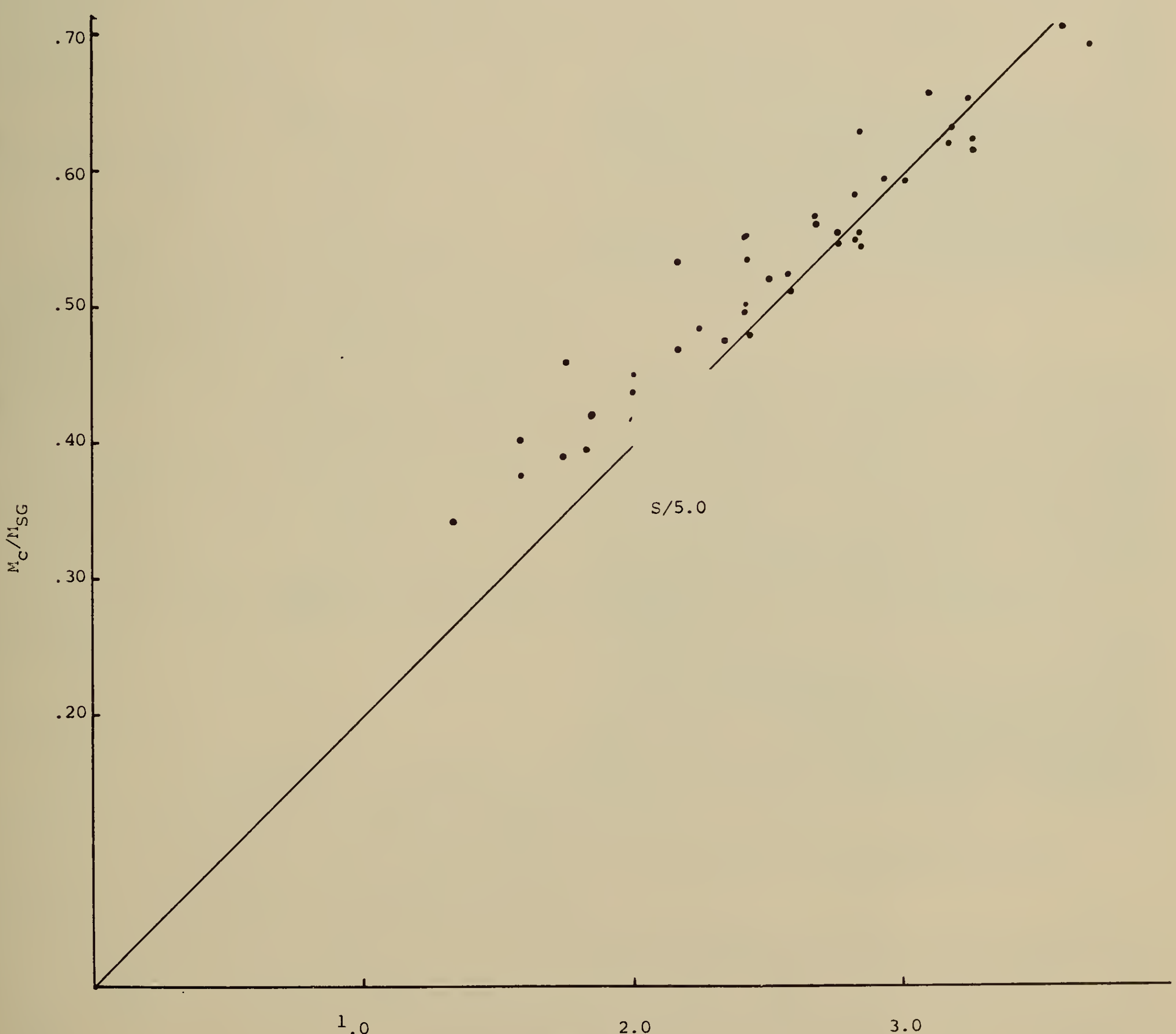


Fig. 5. M_c/M_{SG} vs. girder spacing S.

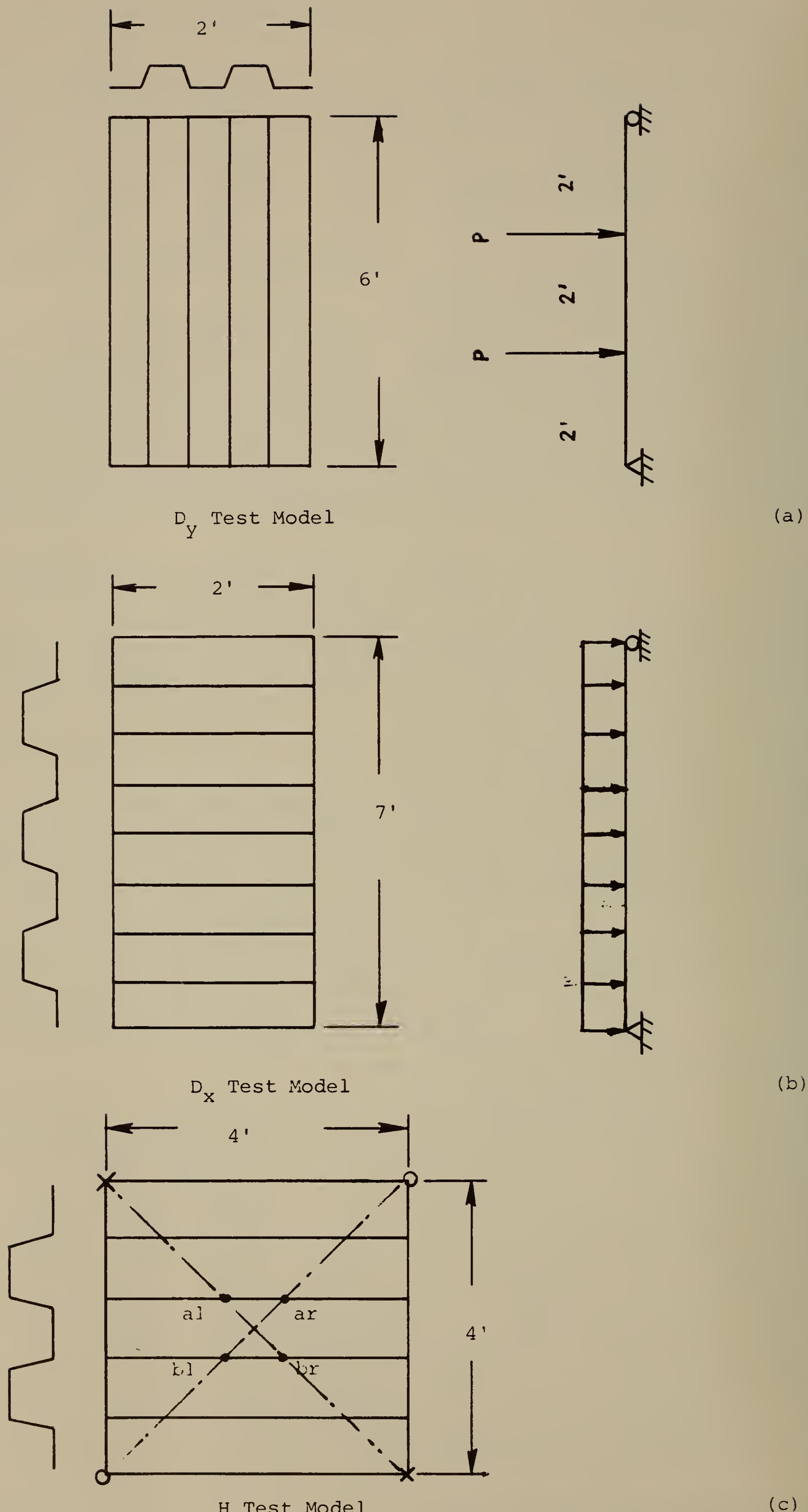


Fig. 6. Test model details.

used in addition to the relationship between load and deformation;

$$W/EI = y^{iv} = (y_{n-2} - 4y_{n-1} + 6y_n - 4y_{n+1} + y_{n+2})/\lambda^4 \quad (3)$$

where W = Load per unit of length and the other terms as previously described.

The total dead load of each specimen was $W_T = .172^K$ (7 gage) and $W_T = .102^K$ (12 gage). The deflection spacing was equal to $\lambda = 6.0''$. Applying Equation (1) where $M = WL^2/8$ and/or Equation (3), the resulting stiffnesses were computed as given in Table 3.

Torsion Stiffness H

Figs. 6(c) and 7(c) show the test arrangement for subjecting a plate to pure torsional moments. The relationship between the induced moments and distortion is given by;

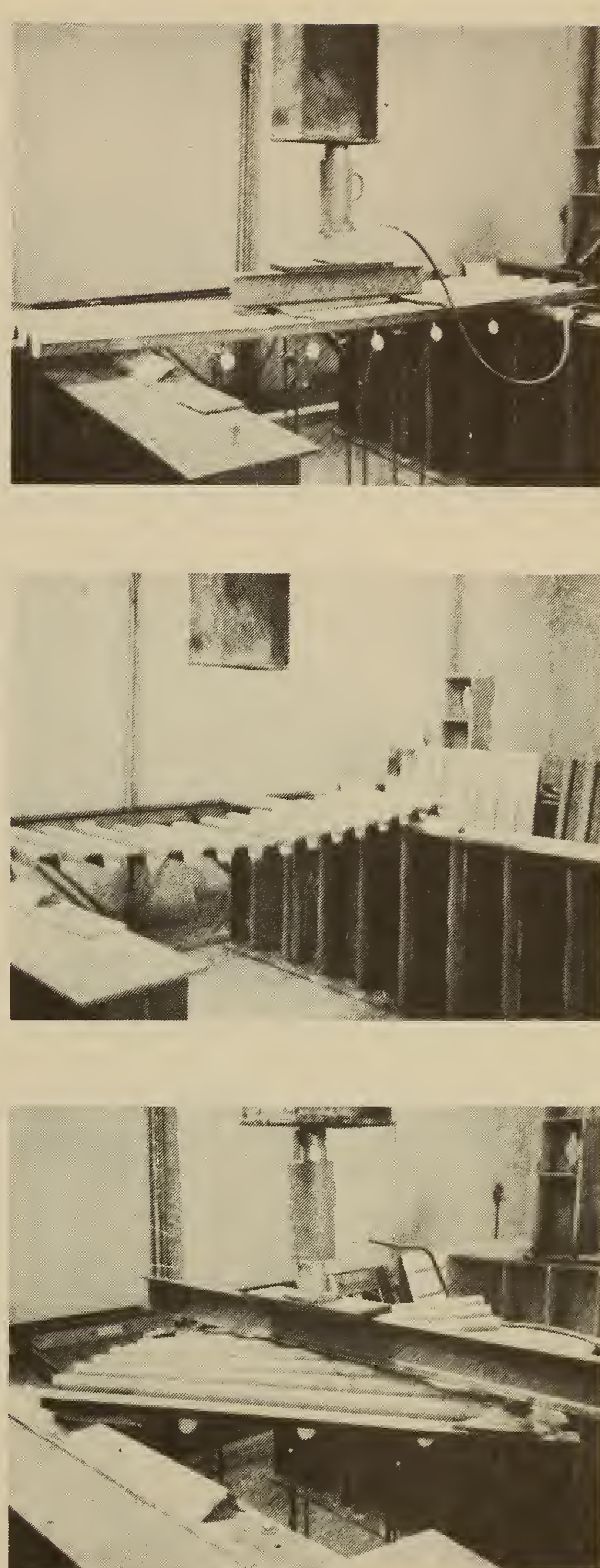
$$M_{xy} = H \frac{\partial^2 w}{\partial x \partial y} = H[(y_{ar} - y_{br}) - (y_{al} - y_{bl})]/4\lambda^4 \quad (4)$$

where the deflections y are measured along the diagonal lines of the plate referenced to the center at distances 6″ horizontal – 6″ vertical, as shown in Fig. 6(c). The induced moment (per unit length) $M_{xy} = P/2$, in which $P_{max} = 600\#$ for 7 gage and $P_{max} = 100\#$ for 12 gage.

The resulting torsional stiffness for each model was computed and is given in Table 3.

Comparison

Table 3, in addition to listing the experimental results, gives the theoretical values as determined from expressions given by Timoshenko (4) assuming a sinusoidal corrugation and those selected for the parametric study. In general, the calculated primary stiffnesses D_y agree with the test data. The secondary stiffnesses D_x are off by a factor of three and the torsional stiffnesses by a factor of two. However, the important parameters in conducting the computer



(a) (b) (c)

Fig. 7. Test model photograph.

study are α and β. As shown by Heins and Perry (3), it is desirable to use a minimum value of β, which was used. Also a variation of α is not significant providing the stiffness D_y is in agreement with the actual tests. Thus, the values of α and β used in the parametric

Table 3.—Test results and theory.

Stiffness	7 Gage Test	7 Gage Ref. (4)	7 Gage Computer Value	12 Gage Test	12 Gage Ref. (4)	12 Gage Computer Value
D_x	5.46	10.50	15.58	1.03	2.06	3.08
D_y	4545.0	5100.	5100.	2934.	3162.	3162.
H	31.65	23.40	15.58	8.07	4.6	3.08
α	.202	.101	.055	.147	.0595	.031
β	.00696	.00459	.0031	.00157	.00152	.00097

study to develop the distribution factors are valid.

Summary

The load distribution of steel bridge planking over flexible girders, when subjected to a series of AASHO wheel loads, has been established as (S/5.0) from a series of analytical studies.

A series of model tests was also conducted to determine the plate rigidity (D_x, D_y, and H) of 7 and 12 gage planking.

Acknowledgments

The author wishes to express his thanks to Graduate Students Mr. A. Kurzwell, Mr. J. Oleinik, Mr. R. Krueger, and Mr. K. Mantro, who performed, in part, the analytical and experimental studies; and also to Messrs. J. H. Boynton, T. C. Phillips, and J. A. Zimmerman of Armco Steel Corporation, who donated their time and material relative to the test models.

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Drilled Human Teeth from the Coast of Ecuador

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ABSTRACT

Dental mutilation of prehistoric human teeth is rare in Ecuador and confined to several examples of gold inlays in young adults from the coastal provinces of Esmeraldas and Guayas. A new example has now been found from the province of Los Rios which further extends the geographic distribution of this custom. The example is the first reported from an old adult and from a new location on the teeth.

The prehistoric aboriginal practice of mutilation of the occlusal and labial surfaces of anterior teeth apparently for esthetic purposes is best known from Middle America, where Romero (1970) has identified over 1,000 examples. These represent 7 distinct types ranging from incisions and notches to drilled perforations with stone inlays. Farther south in Ecuador, reported examples of prehistoric dental mutilations are rare and restricted to drilled perforations inlaid with gold, all found on the coast in the provinces of Guayas and Esmeraldas and dating from the relatively recent Late Integration period.

As early as 1913, Saville summarized all known aboriginal dental inlays from Ecuador: 3 poorly documented examples from the area of Esmeraldas. He reported perforations filled with gold discs on the labial surfaces of the central maxillary incisors of a skeleton from Atacames. The skeleton was found in a "burial tube" on the right bank of the Rio Atacames, just north of the town of that name. The discs are located in the center of the crowns' labial surfaces and measure 6.5 and 5.0 mm in diameter.

Saville (1913:383) cites a second example from the Esmeraldas area containing eight gold inlays in the maxillary incisors and canines. His illustration of the maxilla shows small circular inlays near the occlusal edge of the labial surface.

Saville's final example from the Esmeraldas area consists of gold inlays on 6 maxillary incisors and canines on an isolated skull and mandible found at La Piedra on the bank of the Esmeraldas river at its junction with San Mateo Bay. The teeth contain wide plates of gold, measuring 5 × 8 mm, set into the labial surface 1 mm or more.

More recently, Evans and Meggers (1966:262) have reported an additional example from a chimney-urn burial within an artificial mound farther south, in Guayas Province, Site G-M-5, Elisita (Estrada, 1957:23; fig. 11-A). They illustrate small gold pegs with expanded heads inserted into perforations of 2 incisors and a canine.

Recent examination of human remains excavated by Meggers and Evans in 1961 from Guayas Province has revealed an additional example. Fragmentary human skeletal remains were recovered from a mound urn burial, field cat. no. 1244, La Compañía Site (R-B-3), mound B, on Rio Babahoyo, hacienda La Compañía, coastal Ecuador (unpublished). Associated artifacts suggest the site represents the Milagro phase, Late Integration period (Meggers, 1966:131–142). The presence of European-manufactured artifacts in other areas of the site also suggests a late date, perhaps 16th century A. D. The urn burial producing the human remains contained a considerable quantity of gold, silver, copper, wood and textile

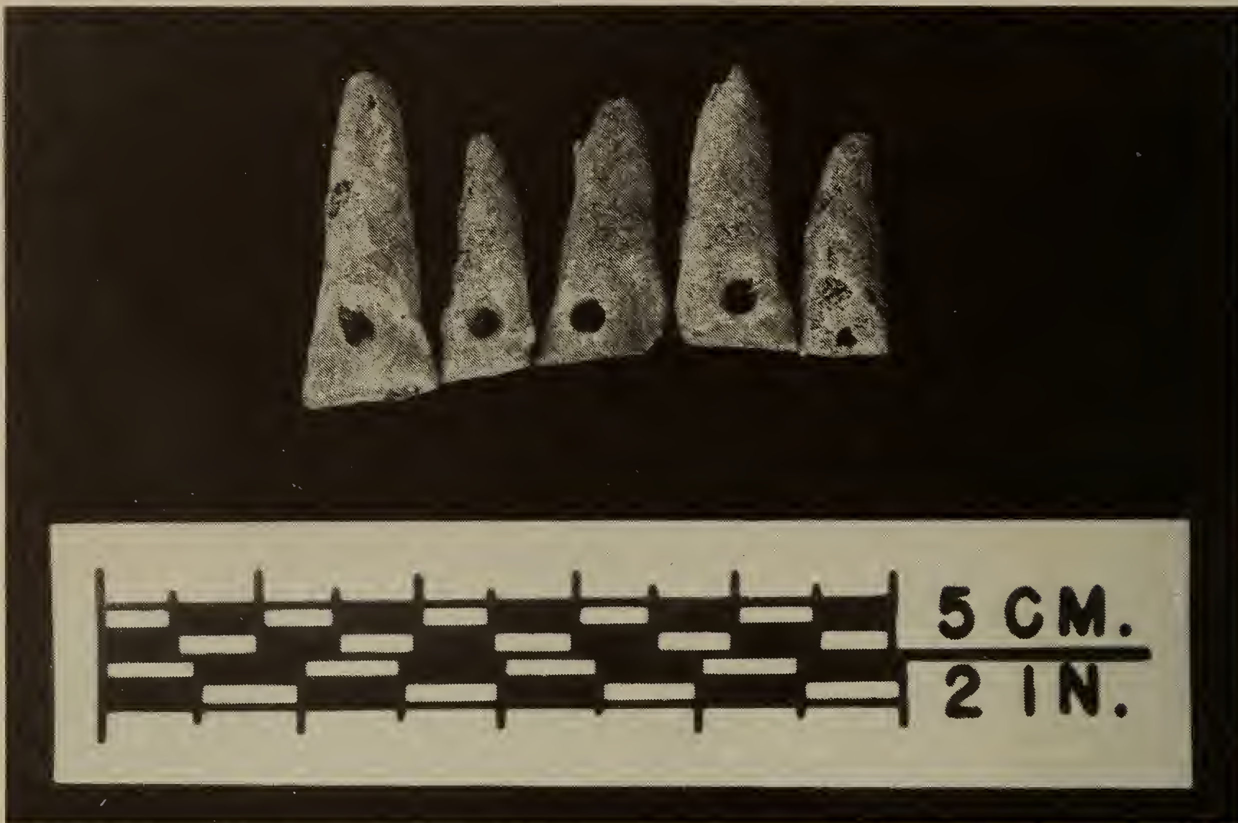

Fig. 1. Drilled teeth (in anatomical order) from La Compañía Site, coastal Ecuador.

artifacts. Contact of the skeletal remains with the copper artifacts produced considerable copper staining on the bone.

The fragmentary skeletal remains represent at least 2 individuals: an adolescent (10 to 15 years) and an adult (35 years+), both of unknown sex. The adult is represented only by 2 cervical vertebrae, the left acromial process of a scapula and 5 teeth. Both vertebrae display osteophytic development corresponding to Stewart's (1958) stage two. The teeth display extensive occlusal wear, with loss of most of the crown and exposure of the pulp cavity. In addition, all teeth but the right lateral incisor display circular, drilled perforations about 2.3 mm in diameter in the center of the buccal surface of the crown, just above the junction of the crown and root (fig. 1). The perforations are about 2 mm deep. Those on the central and right lateral incisors are evenly drilled with sharp borders. The perforation on the canine is more irregular, with a sharp incisal border but a roughened apical border. In addition, a slight indentation occurs at the same location on the left lateral, just below an area where enamel has been chipped away on the labial, occlusal edge of the tooth.

It appears that this adult once had drilled perforations on at least the 4 maxillary incisors and right maxillary canine, probably for the purpose of displaying inlays. The form of the perforation corresponds best with Romero's (1970:51) type El, although due to extensive crown destruction, the possibility of a more elaborate mutilation cannot be ruled out.

The perforations are similar in size to the circular inlays reported by Saville (second example) and by Evans and Meggers, except that the La Compañía perforations are located nearer the crown root junction. In fact, this location distinguishes the new example from possibly all others reported in the New World. Also, as Romero (1970:55) has pointed out, nearly all other examples occur on young adults, with minimal dental attrition. This example is obviously from a much older person, in which attrition has destroyed nearly the entire crown. It is quite possible that the individual once displayed inlays located more occlusally on the crown surface, but lost them with advancing attrition, and subsequently reperforated the teeth on the remaining tooth stump. The continued display of the inlays may have symbolized the status, which the extensive and exotic accompanying grave offerings strongly suggest this individual enjoyed.

Acknowledgments

I thank Betty J. Meggers and Clifford Evans for allowing me to document this example prior to their publication of the final site report. The specimens discussed were collected by them in August 1961, under Project J of the Institute of Andean Research, supported by a grant from the National Science Foundation.

The photograph was prepared by Victor Krantz of the Smithsonian Division of Photographic Services.

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THE AWARDS PROGRAM OF THE ACADEMY AND RECENT HONOREES

The Annual Awards Dinner meeting of the Academy was held on Thursday, March 17, 1977 at the Cosmos Club. Four research scientists and two science teachers were recipients this Spring of the Academy's awards for outstanding scientific achievement. A Special Award was presented to Dr. Mary Louise Robbins of the faculty at George Washington University.

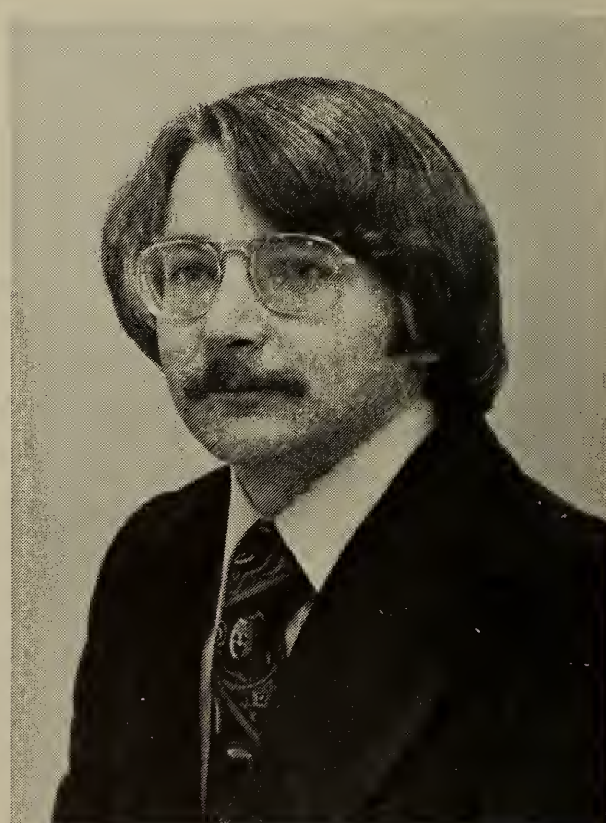
In the area of research, the persons honored were the following: Dr. James H. Howard (Catholic University) for Behavioral Sciences; Dr. Peter H. Fishman (National Institute of Neurological and Communicative Diseases, NIH) for Biological Sciences; Dr. Conrad P. Heins (University of Maryland) for Engineering Sciences; and Dr. Ming-Chang Lin (Naval Research Laboratory) for Physical Sciences.

For the area of Teaching of Science, the Awardee at the college or university level was Dr. J. David Lockard of the Science Teaching Center and Botany Department at the University of Maryland. The recipient of the Berenice G. Lamberton Award for the Teaching of High School Science was Mrs. Johanna B. Donaldson, McLean High School, McLean, Virginia.

The recipient of a Special Award of the Academy was Dr. Mary Louise Robbins, Professor of Microbiology in the George Washington University. This Special Award is a very broad one that includes not only excellence and dedication to teaching, as adjudged by her peers, but also meritorious public service to science in the Washington Area and, in this case, three foreign countries (Egypt, Iraq, and Japan). According to the records of the General Chairman of the Awards Program (Dr. Kelso B. Morris, who made the recommendation), only two other persons in the past 25 years have been given this special recognition. The six awards, as recommended to the General Chairman by the usual Panel Chairmen, and the Special Award, were approved unanimously and with deep appreciation by the Academy's Board of Managers.

Behavioral Sciences

Dr. James H. Howard, Associate Professor of Psychology at The Catholic University of America, was cited for



James H. Howard

"his skillful experimentation on auditory information processing and its cognitive mechanisms."

He was born in Winchester, Mass. In 1969, he completed the B.A. degree *magna cum laude* with a Major in Psychology from Providence College. His Ph.D. in Psychology was completed at Brown University in 1974. Memberships in professional and scientific societies include the American Psychological Association, AAAS, Delta Epsilon Sigma, and Sigma Xi.

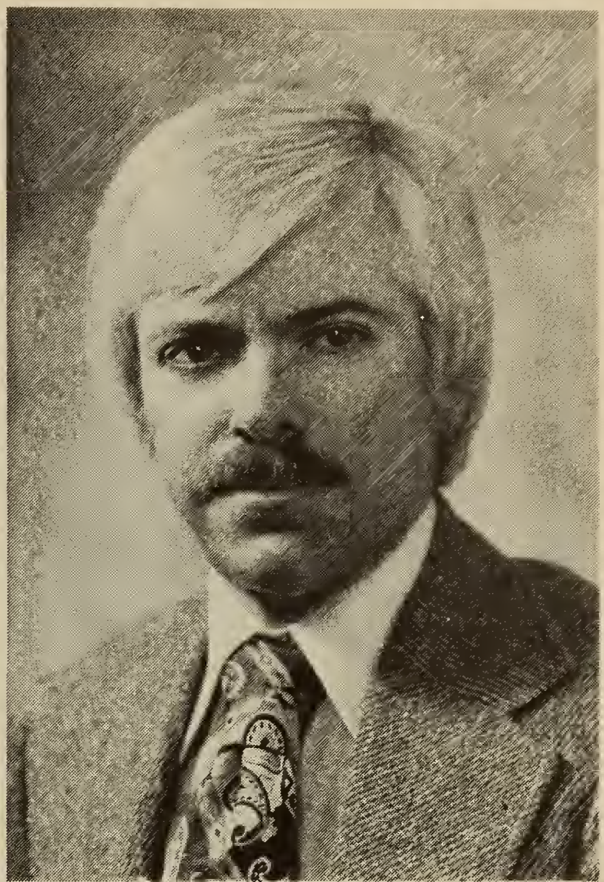
The general area of Dr. Howard's work has been the analysis of cognitive functioning within an information processing perspective. Dr. Howard's ultimate goal, as a target for a life's work, is to outline a theory of auditory pattern recognition that would apply generally to complex speech and non-speech sounds. More immediately, he has concentrated on developing methods to determine the psychologically important characteristics for features of complex non-speech sounds. In his view, until such methods are outlined and tested, we cannot hope to understand the processes involved in auditory recognition.

Biological Sciences

Dr. Peter H. Fishman, Research Biochemist, NINCDS, National Institutes of Health, was cited for "his contributions to the elucidation of gangliosides as biotransducers of membrane-mediated information."

He was born in Boston, Mass. He completed the B.S. degree at Massachusetts Institute of Technology in 1961. His M.S. and Ph.D. degrees were both earned at George Washington University during the period 1965–1970. Special honors held by him include membership in Sigma Xi and the Saunders Teaching Fellowship at George Washington University.

In the six years since Dr. Fishman joined the National Institutes of Health, he has become a world-recognized authority on the mechanism by which environmental messages are received and



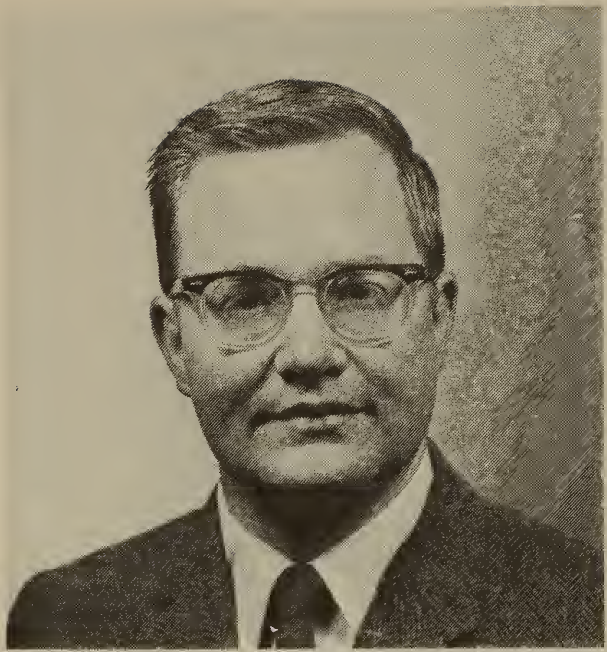
Peter H. Fishman

encoded into the functioning cells. This signaling system involves the interaction of circulating compounds in body fluids such as thyroid-stimulating hormone, chorionic gonadotropin, and luteinizing hormone with specific substances on the surface of cells known as gangliosides. These specific substances were first described over forty years ago. However, only recently has significant progress been made in understanding the function of gangliosides, much of which is attributable to Dr. Fishman's accomplishments.

Engineering Sciences

Dr. Conrad P. Heins, Professor of Civil Engineering at the University of Maryland, was cited for "the development of analytical or design specifications for bridge structures."

He was born in Philadelphia, Pennsylvania. Earned degrees completed by him are the following: BSCE, Drexel Institute (June 1960); MSCE, Lehigh University (June 1962); and Ph.D. Uni-



Conrad P. Heins

Ming-Chang Lin

versity of Maryland, June 1967. Some professional and scientific societies of which he is a member are the ASCE, ACI, SESA, IABSE, ASEE, Sigma Xi, and Chi Epsilon.

Analytical techniques for use in the study of complex bridge systems have been developed by Dr. Heins. These techniques have been used successfully by engineers throughout the country, as well as in England, Germany, Japan, Iran, Spain, Brazil, Wales, Formosa, Africa, Italy, Switzerland, France, Belgium, Poland, and in other parts of the world. He has just published two textbooks, namely, "Bending and Torsional Design in Structural Members" (1975) and "Applied Plate Theory for the Engineer" (1976). Both of these texts incorporate original material developed by Professor Heins. The torsion book has received international acclaim. Moreover, it was selected for the McGraw-Hill BOOK-OF-THE-MONTH-CLUB.

Physical Sciences

Dr. Ming-Chang Lin, Head of the Chemical Kinetics Section at the Naval Research Laboratory, was cited for "the discovery of new chemical lasers and the outstanding application of lasers to chemical problems."

He was born in Hsinchu, Taiwan. His B.S. degree was earned at National Taiwan Normal University in 1959, and his Ph.D. degree was earned at Ottawa University in 1965. Dr. Lin is the author of more than ninety (90) scientific papers and talks in the areas of chemical kinetics and chemical lasers. He was one of the first scientists to recognize the great potential of lasers in synthetic chemistry. He suggested using a laser to activate a specific chemical bond so that the reaction would take place at that position. Dr. Lin's pioneering study in this area involved the reaction of ozone and nitric oxide.

For the years 1971 and 1974, he received NRL's Chemistry Division Award for the best research papers originating in that laboratory. In 1975, Dr. Lin was the recipient of the Hillebrand Award from the Chemical Society of Washington.

Teaching of Science
(College Level)

Dr. J. David Lockard, a Professor in the Science Teaching Center and Department of Botany at the University of Maryland, was cited for his "outstanding state, national, and international leadership in science education."

He was born in Renovo, Pennsylvania.

J. David Lockard

Johanna Bernice Donaldson

At the Pennsylvania State University he earned a B.S. degree in 1951; a M.Ed. degree in 1955, and a Ph.D. (Botany) in 1962. Dr. Lockard has held the position of Director of the Science Teaching Center & the International Clearing House on Science and Mathematics at the University of Maryland since 1962.

Professional and scientific societies in which he holds membership include the following: AAAS (Fellow); Botanical Society of America; Maryland Association of Science Teachers; NSTA; Washington Academy of Sciences; and Sigma Xi. In 1974, the National Science Teachers Association awarded him a citation for Distinguished Service to Science Education.

Teaching of Science
(High School Level)
(The Berenice G. Lamberton Award)

Mrs. Johanna Bernice Donaldson, of McLean High School (A Fairfax County, Va., school) was cited as "an outstanding teacher in earth sciences and pioneer

Mary Louise Robbins

in oceanic studies." In May 1976, the Joint Board on Science and Engineering Education of the Greater Washington Area honored Mrs. Donaldson with their "Excellence in Teaching of Science" Award. On November 10, 1976, she presented to all Fairfax County Area III Principals a program on "The Importance of Oceanic Studies and Implementing Courses in Secondary Schools."

Public Service and Teaching of Science
Special Award

Dr. Mary Louise Robbins, Professor of Microbiology in the George Washington University School of Medicine, was cited for her intense dedication as a superior teacher in the field of virology at local, national, and international levels and as one whose students are carrying the torch of true science into new and varied fields.

She was born in St. Paul, Minnesota. Her training in science was received at the following institutions: B.A. with Major in Biology at The American University, 1934; M.A. in Bacteriology at the George Washington University, 1940; and Ph.D. in Bacteriology at The George Washington University, 1944. In 1949, she received personal training in virology at the Harvard Medical School, Boston, Mass. under Monroe D. Eaton and John F. Enders. For the period 1971–1972, she served as President of the Washington Academy of Sciences. One scientist has observed that it is amazing that Dr. Robbins has found the time to publish 52 research papers (including 17 abstracts) and still enrich her courses with materials from most of those articles.

Among her students, one can list the following who found her to be a most inspiring teacher: Dr. Anne Bourke; Dr. Kenneth Takamoto; Dr. Janet Hartley; Dr. Ariel Hollingshead; and Dr. Daniel Kundin. Dr. Robbins holds membership in ten professional organizations and is listed in nine biographical publications.

NEW FELLOWS

Ronald W. Manderscheid, Research Sociologist, National Institute of Mental Health, HEW., in recognition of his work in social psychology, and in particular his theoretical work on the social and psychological effects of micro-physical environments, his research on alienation, and his contribution to empirical assessments of mental health interventions. *Sponsor*: Richard H. Foote.

Phillip E. Sokol, President, Gillette Res. Institute, in recognition of his contribution to cosmetic science, in particular his studies of keratin chemistry, polymer syntheses and application, and novel dye syntheses and application. *Sponsors*: Charles A. Rader, Norman R. Hollies.

F. Christian Thompson, Research Entomologist, USDA., in recognition of his studies on the biogeography of insects, and in particular his research on the taxonomy and systematics of the fly family Syrphidae. *Sponsors*: Richard H. Foote, Ashley B. Gurney.

Patricia A. Sarvella

Dr. Patricia A. Sarvella, 50, a research geneticist for the Agricultural Research Service in Beltsville, died on March 8, 1977, of cancer in Prince Georges County Hospital. She lived on Dove Circle in Laurel, Md.

Dr. Sarvella was executive vice president of the Organization of Professional Employes of the Department of Agriculture, associate director and awards chairman of the Prince Georges Science Fair Association, lieutenant governor of District 16 of Pilot Club International and a former president of the American Association of University Women's medical division. She was program chairman of the Washington Academy of Sciences.

A native of Waukeegan, Ill., Dr. Sarvella held a B.S. degree from Case-Western University and a Ph.D. in genetics from North Carolina State University. She also studied in Sweden and Washington State University and taught at Mississippi State University.

She leaves a brother, John R., of Alexandria.

L. Edwin Yocum

Dr. L. Edwin Yocum, 86, died at his home in Clearwater, Florida on 23 February 1977. A plant physiologist, he taught botany at George Washington University for 25 years and was head of the Botany Department there for 8 years. He had been retired for 25 years at the time of his death. Interment was in Pennsylvania.

JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES

Instructions to Contributors

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Directory Issue

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Directory, 1977:

Washington Academy of Sciences

Founded in 1898

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The Journal

This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

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Electrochemical Society	Delegate not appointed
Washington History of Science Club	Inactive
American Association of Physics Teachers	To be appointed
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Human Factors Society	H. McIlvaine Parsons

Delegates continue in office until new selections are made by the representative societies.

THE DIRECTORY OF THE ACADEMY FOR 1977

Foreword

The present, 52nd issue of the Academy's directory is again this year issued as part of the September number of the Journal. As in previous years, the alphabetical listing is based on a postcard questionnaire sent to the Academy membership. Members were asked to update the data concerning address and membership in affiliated societies by June 30, 1977. In cases in which cards were not received by that date, the address appears as it was used during 1977, and the remaining data were taken from the directory for 1976. Corrections should be called to the attention of the Academy office.

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Vice-President:	George T. Armstrong, 1401 Dale Dr., Silver Spring, MD. 20910
Secretary:	James F. Goff, 3405 34th Pl., N.W., Washington, D.C. 20016
Delegate:	James F. Goff

2 Anthropological Society of Washington (1898)

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President-elect:	Ruth Lardman, Dept. of Anthropology, American Univ., Washington, D.C. 20016
Secretary:	Mary F. Gallager, Montgomery College, Rockville, MD. 20853
Delegate:	Jean K. Boek, National Graduate Univ., 3408 Wisconsin Ave., N.W., Washington, D.C. 20016

3 Biological Society of Washington (1898)

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Delegate:	William R. Heyer, Amphibian & Reptiles, Nat. History Bldg., Smithsonian Institution, Washington, D.C. 20560

4 Chemical Society of Washington (1898)

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Vice-President:	David H. Freeman. Univ. of Md. College Park, MD. 20742
Secretary:	George Mushrush, George Mason Univ. Fairfax, VA. 22030
Delegate:	David H. Freeman

5 Entomological Society of Washington (1898)

President:	Maynard J. Ransay, Rm. 660, Federal Bldg., Hyattsville, MD. 20782
President-elect:	Douglas W. S. Sutherland, 125 Lakeside Dr. Greenbelt, MD. 20770
Secretary:	Donald R. Whitehead, Rm. W-619, U.S. National Museum of Natural History, Washington, D.C. 20560
Delegate:	Maynard J. Ramsay

6 National Geographic Society (1898)

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Chairman:	Melvin M. Payne, National Geographic Society, Washington, D.C. 20036
Secretary:	Owen R. Anderson, National Geographic Society, Washington, D.C. 20036
Delegate:	T. Dale Stewart, Smithsonian Institution, Museum of Natural History, Washington, D.C. 20560

7 Geological Society of Washington (1898)

President:	Francis R. Boyd, Jr., Carnegie Institution of Washington, Geophysical Lab., 2801 Upton St., N.W., Washington, D.C. 20008
Vice-President:	J. Thomas Dutro, U.S. Geological Survey, Branch of Paleontology and Stratigraphy, U.S. National Museum, Washington, D.C. 20560
Secretary:	William E. Davies, U.S. Geological Survey, Reston, Va. 22092, Mail Stop 973
Delegate:	Marian M. Schnepfe, 2019 Eye St. N.W. #402, Washington, D.C. 20006

8 Medical Society of the District of Columbia (1898)

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President-elect: Frank S. Bacon
Secretary: Thomas Sadler
Delegate: Not appointed

9 Columbia Historical Society (1899)

President: Wilcomb E. Washburn, Amer. Studies, S.I., Washington, D.C. 20560
Vice-President: William H. Press, 1511 K St., N.W., Washington, D.C. 20005
Secretary: Marcellina Hummer, 2006 Columbia Rd., N.W., Washington, D.C. 20009
Delegate: Paul H. Oehser, National Geographic Society, Washington, D.C. 20036

10 Botanical Society of Washington (1902)

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Secretary: James J. White, Dept. of Botany, Smithsonian Institution, Washington, D.C. 20560
Delegate: Conrad B. Link, Univ. of Md., Dept. of Horticulture, College Park, Md. 20742

11 Society of American Foresters, Washington, Section (1904)

Chairman: Arthur V. Smith, 3301 Wessynton Way, Alexandria, Va. 22309
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Delegate: T. B. Glazebrook, 7809 Bristow Dr., Annandale, Va. 27007

12 Washington Society of Engineers (1907)

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Secretary: John A. Waring, 8502 Flower Ave., Takoma Park, Md. 20012
Delegate: George Abraham, 3107 Westover Dr., S.E., Washington, D.C. 20020

13 Institute of Electrical & Electronics Engineers, Washington Section (1912)

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Delegate: George Abraham, 3107 Westover Dr., S.E., Washington, D.C. 20020

14 American Society of Mechanical Engineers, Washington Section (1923)

Chairman: Michael Chi, 2721 24th St. N., Arlington, Va. 22207
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Secretary: Ron Niebo, 8587 Brae Brook Dr., Lanham, Md. 20801
Delegate: Michael Chi

15 Helminthological Society of Washington (1923)

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Vice-President: Harley G. Sheffield, Lab. of Parasitic Diseases, NIH, NOAID, Bldg. 5, Bethesda, Md. 20014
Secretary: J. Ralph Lichtenfels, Animal Parasitology Inst., Bldg. 1080, BARC-East, Beltsville, Md. 20705
Delegate: Robert S. Isenstein, Animal Patasitology Inst., Bldg. 1040, BARC-East, Beltsville, Md. 20705

16 American Society for Microbiology, Washington Branch (1923)

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Vice-President: Irvin C. Mohler, The George Washington University School of Medicine, Dept. of Medical & Public Affairs, Washington, D.C. 20037
Secretary: Phyllis D. Kind, The George Washington University School of Medicine, Dept. of Microbiology, Washington, D.C. 20037
Delegate: Michael J. Pelczar, Jr., Vice President for Graduate Studies & Research, University of Md., College Park, Md. 20742

17 **Society of American Military Engineers, Washington Post (1927)**

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Vice-President:	Col. Rodney Cox, DAEN-FEZ-B, Washington, D.C. 20314
Secretary:	Lt. Jim Delkar, Code 0632, NAVFAC Hdqtrs., 200 Stovall St., Alexandria, Va. 22310
Delegate:	Hal P. Demuth, 4025 Pine Brook Rd., Alexandria, Va. 22310

18 **American Society of Civil Engineers, National Capital Section (1942)**

President:	James W. Harland, 1511 K St., N.W., Suite 337, Washington, D.C. 20005
Vice-President:	Norman L. Cooper, Dept. of Transportation, 400 7th St., Rm. 9422, Washington, D.C. 20590
Secretary:	Robert Efimba, Dept. of Civil Engineering, Howard University, Washington, D.C. 20059
Delegate:	Robert Sorenson, Coastal Engineering Research Ctr., Kingman Bldg., Ft. Belvoir, Va. 22060

19 **Society for Experimental Biology & Medicine, D.C. Section (1952)**

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President-elect:	Cyrus R. Creveling, 4516 Amherst Lane, Bethesda, Md. 20014
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Delegate:	Donald F. Flick, 930 19th St., So., Arlington, Va. 22202

20 **American Society for Metals, Washington Chapter (1953)**

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Vice-Chairman:	Alan H. Rosenstein, Air Force Office of Scientific Res., 1400 Wilson Blvd., Arlington, Va. 22209
Secretary:	Joseph Malz, NASA, Code RWM, Washington, D.C. 20546
Delegate:	Glen W. Wensch, U.S. Atomic Energy Comm., Washington, D.C. 20545

21 **International Association for Dental Research, Washington Section (1953)**

President:	Donald W. Turner, Dental Sciences Dept., Naval Med. Res. Inst., NNMC, Bethesda, Md. 20014
Vice-President:	John D. Termine, Natl. Institute of Dental Research, Bethesda, Md. 20014
Secretary:	William R. Cotton, Naval Medical Research Institute, Bethesda, Md. 20014
Delegate:	William V. Loebenstein, National Bureau of Standards, Washington, D.C. 20234

22 **American Institute of Aeronautics and Astronautics, National Capital Section (1953)**

Chairman:	Paul J. Waltrup, John Hopkins University, Applied Physics Lab., Johns Hopkins Rd., Laurel, Md. 20810
Vice-Chairman:	Robert O. Bartlett, Goddard Space Flight Ctr., Greenbelt, Md. 20771
Secretary:	George J. Vila, General Dynamics, 1025 Conn. Ave., N.W., Washington, D.C. 20036
Delegate:	George J. Vila

23 **American Meteorological Society, D.C. Chapter (1954)**

Chairman:	Thomas D. Potter, Environmental Data Serv. DXI, Page Bldg. No. 2, Washington, D.C. 20235
Vice-Chairman:	Celso Barrientos, Natl. Weather Serv. W427, 821 Gramax Bldg., 8060 13th St., Silver Spring, Md. 20910
Secretary:	Richardson Decker, SPO/Natl. Weather Serv., Gramax Bldg., 8060 13th St., Silver Spring, Md. 20910
Delegate:	A. James Wagner, National Weather Service, World Weather Bldg., 5200 Auth Rd., Washington, D.C. 20233

24 **Insecticide Society of Washington (1959)**

Chairman:	Neal O. Morgan, USDA, ARS, Bldg. 476, Rm. 100, BARC-East, Beltsville, Md. 20705
Chairman-elect:	Jack R. Plimmer, USDA, ARS, Bldg. 306, Rm. 313, BARC-East, Beltsville, Md. 20705
Secretary:	John Neal, ARS, ARC, Bldg. 467, Beltsville, Md. 20705
Delegate:	Robert Argauer, ARS, ARC, Bldg. 309, Beltsville, Md. 20705

25 **Acoustical Society of America (1959)**

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Vice-Chairman:	Charles T. Molloy, 2400 Claremont Dr., Falls Church, Va. 22043

Secretary: William K. Blake, Naval Ship R & D Ctr., Bethesda, Md. 20034
Delegate: None appointed

26 American Nuclear Society, Washington Section (1960)
President: B. E. Leonard, Institute for Resource Management, 4948 St. Elmo Ave. Bethesda, Md. 20014
Vice-President: Ray Durante, Westinghouse Electric, 1801 K St., N.W., Washington, D.C. 20006
Secretary: S. Bassett, NUS Corp., Rockville, Md. 20852
Delegate: Dick Duffy, Nuclear Engineering, Univ. of Md., College Park, Md. 20742

27 Institute of Food Technologists, Washington Section (1961)
Chairman: Tannous Khalil, Giant Foods, Inc., Landover, Md. 20785
Vice-Chairman: Florian C. Majorack, Food & Drug Adm., Washington, D.C.
Secretary: Glenn V. Brauner, National Canners Assoc., Washington, D.C. 20036
Delegate: William Sulzbacher, 8527 Clarkson Dr., Fulton, Md. 20759

28 American Ceramic Society, Baltimore-Washington Section (1962)
Chairman: W. T. Bakker, General Refractories Co., P.O. Box 1673, Md. 21203
Chairman-elect: L. Biller, Glidden-Dirkee Div., SCM Corp., 3901 Hawkins Point Rd., Baltimore, Md. 21226
Secretary: Edwin E. Childs, J. E. Baker Co., 232 E. Market St., York, Pa. 17405
Delegate: None appointed

29 Electrochemical Society, National Capital Section (1963)
Chairman: Judith Ambrus, Naval Surface Weapons Ctr., White Oak, Md. 20910
Vice-Chairman: John B. O'Sullivan, 7724 Glenister Dr., Springfield, Va. 22152
Secretary: John Ambrose, NBS, Washington, D.C. 20234
Delegate: None appointed

30 Washington History of Science Club (1965)
Chairman: Richard G. Hewlett, Atomic Energy Comm.
Vice-Chairman: Deborah Warner, Smithsonian Institution
Secretary: Dean C. Allard
Delegate: None appointed

31 American Association of Physics Teachers, Chesapeake Section (1965)
President: William Logan, D.C. Teachers College, 2565 Georgia Ave., Washington, D.C. 20001
Vice-President: Eugenie V. Mielczarek, George Mason Univ., 4400 University Dr., Fairfax, Va. 22030
Secretary: John B. Newman, Towson State College, Towson, Md. 21204
Delegate: None appointed

32 Optical Society of America, National Capital Section (1966)
President: Lucy B. Hagan, National Bureau of Standards, Rm. B360, Physics Bldg., Washington, D.C. 20234
Vice-President: M. Kent Wilson, 1800 G. St., N.W., Rm. 518, Washington, D.C. 20006
Secretary: L. Douglas Ballard, Bldg. 226, Rm. 317, National Bureau of Standards, Washington, D.C. 20234
Delegate: Lucy B. Hagan

33 American Society of Plant Physiologists, Washington Section (1966)
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Vice-President: Anne H. Datko, NIMH Bldg. 32A, Rm. 101, Bethesda, Md. 20014
Secretary: Werner J. Meudt, USDA, ARS, Beltsville, Md. 20705
Delegate: W. Shropshire, Jr., Smithsonian Institution, 12441 Parklawn Dr., Rockville, Md. 20852

34 Washington Operations Research Council (1966)
President: Gerald R. McNichols, 8101 Rondelay Lane, Fairfax Station, Va. 22039
Vice-President: Charles Tiplitz, 8809 Bells Mills Rd., Potomac, Md. 20854
Secretary: Thomas Sicilia
Delegate: John G. Honig, 7701 Glenmore Spring Way, Bethesda, Md. 20034

35 Instrument Society of America, Washington Section (1967)
President: Francis C. Quinn
President-elect: John I. Peterson
Secretary: Frank L. Carou
Delegate: None appointed

36 American Institute of Mining, Metallurgical & Petroleum Engineers (1968)

Chairman: Gus H. Goudarzi, U.S. Geological Survey, Natl. Ctr., Mail Stop 920. Reston, Va. 22092

Vice-Chairman: Garrett R. Hyde, U.S. Bureau of Mines, College Park Metallurgy Res. Ctr., College Park, Md. 20740

Secretary: Ronald A. Munson, U.S. Bureau of Mines, Division of Metallurgy, 2401 E. St., N.W., Washington, D.C. 20241

Delegate: Phil W. Guild, U.S. Geological Survey, Natl. Ctr., Mail Stop 952, Reston, Va. 22092

37 National Capital Astronomers (1969)

President: Benson J. Simon, 8704 Royal Ridge Lane, Laurel, Md. 20811

Vice-President: Geoffrey Hornseth, 8806 W. Fort Foote Terrace, Oxon Hill, Md. 20022

Secretary: William R. Winkler, 15804 Pinecroft Lane, Bowie, Md. 20716

Delegate: Benson J. Simon

38 Maryland-District of Columbia and Virginia Section of Mathematical Assoc. of America (1971)

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Secretary: Reuben Drake, 3701 Connecticut Ave., N.W., Washington, D.C. 20008

Delegate: Patrick Hayes, 950 25th St. N.W., Washington, D.C. 20037

39 D.C. Institute of Chemists (1973)

President: Kelso B. Morris, 1448 Leegate Rd., N.W., Washington, D.C. 20012

President-elect: Leo Schubert, 8521 Beech Tree Rd., Bethesda, Md. 20034

Secretary: Fred D. Ordway, 2816 Fall Jax Dr., Falls Church, Va. 22042

Delegate: Milosiav Rechcigl, Jr., 1703 Mark Lane, Rockville, Md. 20852

40 The D.C. Psychological Association (1975)

President: Richard P. Youniss, Dept. of Psychology, Catholic Univ., Washington, D.C. 20064

Vice-President: John F. Borriello, St. Elizabeth's Hospital, Overholser Division, Washington, D.C. 20032

Secretary: Eugene Stammeyer, St. Elizabeth's Hospital, Overholser Division, Washington, D.C. 20032

Delegate: John J. O'Hare, Office of Naval Research, 800 N. Quincy St., Arlington, Va. 22217

41 The Washington Paint Technical Group (1976)

President: David T. Bloodgood, Bethlehem Steel Corp., CTD Shipbuilding, Sparrows Point, Md. 21219

Vice-President: Leon S. Birnbaum, 5117 Kenwood Dr., Annandale, Va. 22003

Secretary: Mildred A. Post, National Bureau of Standards, Bldg. 226, Rm. B-348 Washington, D.C. 20234

Delegate: Paul G. Campbell, National Bureau of Standards, B-348 Br., Washington, D.C. 20234

42 Potomac Division, American Phytopathological Society (1977)

President: F. M. Latterell, Plant Disease Lab., USDA, P.O. Box 1209, Frederick, Md. 21701

Vice-President: C. W. Roane, Dept. of Plant Path., Va. Polytech. Inst., Blacksburg, Va. 24061

Secretary: J. R. Stavely, Tobacco Lab., USDA, BARC-West, Beltsville, Md. 20705

Delegate: Tom van der Zwet, USDA, Fruit Lab., Rm. 12, Bldg. 004, BARC-West, Beltsville, Md. 20705

43 Metropolitan Washington Chapter of the Society for General Systems Research (1977)

Chairman: Ronald W. Manderscheid, 212 West Montgomery Ave., Rockville, Md. 20850

Delegate: Ronald W. Manderscheid

44 Potomac Chapter, Human Factors Society (1977)

President: Harry J. Older, 3527 Saylor Place, Alexandria, Va. 22304

President-elect: Dean M. Havron, Human Sciences Research Inc., 7710 Old Springhouse Rd., McLean, Va. 22101

Secretary: Marshall A. Narva, 2 Infield Court, South, Rockville, Md. 20854

Delegate: H. McIlvaine Parsons, Institute for Behavioral Res., Inc., Silver Spring, Md. 20910

Alphabetical List of Members

M = Member; F = Fellow; E = Emeritus member L = Life Fellow. Numbers in parentheses refer to numerical code in foregoing list of affiliated societies.

A

ABELSON, PHILIP H., Ph.D., Carnegie Inst. of Washington, Carnegie Institution of Washington, 1530 P St., N.W., Washington D.C. 20005 (F-1, 4, 7, 16)
ABRAHAM, GEORGE, M.S., Ph.D., 3107 Westover Dr., S.E., Washington, D.C. 20020 (F-1, 6, 12, 13, 31, 32)
ACHTER, M. R., Code 6416, U.S. Naval Research Lab., Washington, D.C. 20375 (F-20, 36)
ADAMS, CAROLINE L., 242 North Granada St., Arlington, Va. 22203 (E-10)
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ADRIAN, FRANK J., Applied Phys. Lab., Johns Hopkins Univ., Laurel, Md. 20810 (F)
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ALBUS, JAMES S., 4515 Saul Rd., Kensington, Md. 20014 (F)
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Potomac Division, American Phytopathological Society

Objectives: To bring together plant pathologists to discuss research in plant pathology and other problems of general interest and to stimulate understanding with other sciences concerned with the general problem of crop improvement.

Members: Active members must be members of the American Phytopathological Society. Persons who are not members of the APS but are interested in plant pathology are eligible for Associate Membership. Retired plant pathologists are considered honorary members.

There are 238 members (from D.C., Md., Va., Del., N.J., N.C., & Yonkers, N.Y.) in the Division.

Meetings: One principal meeting is held each year with formal programs of scientific interest. At the 1976 meeting held at the Univ. of Delaware on March 17–19, a total of 50 papers were presented before various groups.

Metropolitan Washington Chapter of the Society for General Systems Research

Objectives: (1) To investigate the isomorphy of concepts, laws and models from various fields, and to help in useful transfers from one field to another: (2) to encourage development of adequate theoretical models in fields which lack them: (3) to minimize the duplication of theoretical effort in different fields: and (4) to promote the unity of sciences through improving communication among specialists.

Members: The membership is composed of professional, scientific, and academic people whose interests are broader than a particular discipline and who are pursuing the systems point of view for dealing with complex problems. There are now 100 members in the Washington Chapter.

Meetings: The chapter sponsors an annual meeting at which papers are presented and research areas discussed. The 1975 meeting held Sept. 19–20 was concerned with "Systems Science and the Future of Health." The topic of the 1976 meeting is to be "Complexity: A Challenge to the Adaptive Capacity of American Society."

Potomac Chapter, Human Factors Society

Objectives: To (1) provide a professional forum for the exchange of multidisciplinary ideas and information about man and his environment: (2) encourage a social relationship where members can meet and communicate freely with others who have a wide variety of viewpoints and backgrounds: (3) establish a point of contact for persons and organizations in the Potomac Chapter area who are interested in or have a need for human factors research and technology.

Members: Must be members of the National Society. Individuals not qualifying for the election to the grade of member who are interested or active in the field may become associate members. Such members may not vote or become officers. The chapter consists of 181 members.

Meetings: Not less than one regular meeting is held each year. Special meetings may be called on request of 15 members. The principal 1975 meeting was a one day symposium on "Advance Technologies in Systems Operation and Control." In 1976 there was a one-day symposium on "Training: Technology to Policy."

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A Century of Cryogenics[1]

R. P. Hudson

Chief, Heat Division, National Bureau of Standards, Washington, D. C. 20234

Bicentennial themes being in vogue these days, something of that nature might be expected of me on this occasion. In the case of cryogenics, the topic of my choice, there is an obvious and insuperable problem, however. Facing facts, therefore, and with the thought that "half a loaf is better than none," we must settle for a single century!

I propose to give you a rapid, not heavily technical survey of the major developments in the history of low temperature physics. Given the complexity of the subject and the short time available, the treatment must be extremely superficial but perhaps, in its variety, you will find it interesting.

The phrase *low temperature* means quite different things to the layman and the physicist. The latter is talking about the region near absolute zero—perhaps a few words here about temperature itself will be helpful. Scientists measure temperature upward from absolute zero, avoiding negative numbers, thus the term *absolute temperature*. Apart from this, the scientific (or thermodynamic, or Kelvin) scale is the same as the Celsius scale. In Table 1 is a chart of equivalent temperatures on the most familiar and widely used scales.

A very great part of low temperature research is carried out between 0 and 1K. The question naturally arises, "What is so interesting about that last one degree?" Here, it helps to think in terms of energy—the quantity kT (where k is the Boltzmann constant, equal to 1.38×10^{-16} erg K^{-1}), which can be considered as the *quantum of thermal energy*, expresses the "shaking up effect" of the temperature, T. Whether a particular temperature, T, can cause any significant excitation within a system will depend upon what system we are talking about—*i.e.*, upon the relative size of the thermal energy, kT, and that of the dominant energy states of the system.

Different physical phenomena occur in different regions of the temperature scale because the pertinent, allowed energy states are of tremendously varying energy *magnitude*. So we must purge our thoughts of this everyday, humanistic concept that one degree is *always* "small beans," although it certainly is in a 300° world. Let us look at the diagram of Fig. 1. Here the temperature scale is depicted logarithmically. Life on earth dwells within a small part of a single decade and all major industrial activities span less than two decades. "Cryogenics" is 100K on down, and "cryophysics" 4K on down, in usual parlance.

As a final introductory remark, I shall now and again use the term *entropy*, which is one of the thermal state de-

[1] Address of the retiring president, Philosophical Society of Washington, January 16, 1976. Many illustrations used in the course of the oral presentation have been omitted from this printed version.

Table 1.—Temperature equivalents.

Descriptor	Fahrenheit temperature	# of °F above 32°F	5/9 of # in preceding column	Celsius temperature	Kelvin temperature
Melting point of gold	1947.97°F	1915.97	1064.43	1064.43°C	1337.58K
Melting point of lead	621.504°F	589.504	327.502	327.502°C	600.652K
Boiling point of water	212°F	180	100	100°C	373.15K
Typical summer day temperature	86°F	54	30	30°C	303.15K
Typical winter day temperature	41°F	9	5	5°C	278.15K
Freezing point of water	32°F	0	0	0°C	273.15K
"Forty below"	−40°F	−72	−40	−40°C	233.15K
Boiling point of oxygen	−297.332°F	−329.332	−182.962	−182.962°C	90.188K
Boiling point of helium	−452.067	−484.067	−268.926	−268.926°C	4.224K

scriptors of a system and which is frequently much more revealing than T. In Fig. 2 I present some definitions, within the language of thermodynamics. [From a statistical mechanics point of view we know that S is a measure of *disorder*.] Certain commonly encountered experimental manipulations at low temperatures are most perspicuously diagrammed on an entropy plot.

Early Developments

The history of the development of low-temperature physics is intimately bound with the liquefaction of gases, especially the so-called "permanent gases."

At the end of 1877 (note the desirable century span!) a permanent gas was first liquefied, by expansion from high pressure. This was achieved almost simultaneously, for air (as a fog) by Cailletet in France and for oxygen (as a liquid jet) by Pictet in Switzerland. In April 1883, in Cracow, the Polish scientists Wroblewski and Olzewski convincingly liquefied (i.e., collected) oxygen, and then nitrogen.

Hydrogen remained obdurate until 1898 when Dewar succeeded, using the expansion-plus-regenerative-cooling technique (below). In the meantime, Ramsey had, in 1895, isolated the elemental substance *helium*, but this was to remain unliquefiable for another decade.

The Liquefaction Process

The diagram in Fig. 3 represents a hypothetical fluid on an S-T chart. The curve is a line of fixed pressure, say, 1 atmosphere. Consider a simple expansion of a compressed, thermally-isolated gas at some starting temperature, T_0: reduction of the pressure, P, causes an excursion from right to left on a horizontal (constant entropy) path and expansion to 1 atmosphere brings the system to the 1 atmosphere line CDA. If the section CD is encountered, we shall have reached the normal boiling point, T_b, and have produced liquid. However, if this graph represents nitrogen, for instance, and T_0 represents room temperature, one would require a pressure of 10^6 atmospheres to reach point B!

The heat exchanger, or heat regenerator, principle enables one to use much smaller pressure ratios:- the expanded gas is used to precool incoming gas, which starts *its* expansion at a lower temperature and hence cooling is progressive.

The lower the boiling point, the harder it is to make the liquefaction process work without excellent thermal insulation. The necessary insulation is furnished by a container which is common to the domestic scene and familiar to us all as the thermos or vacuum flask. It was first used in this connection by Dewar in 1892; scientists today call them dewar

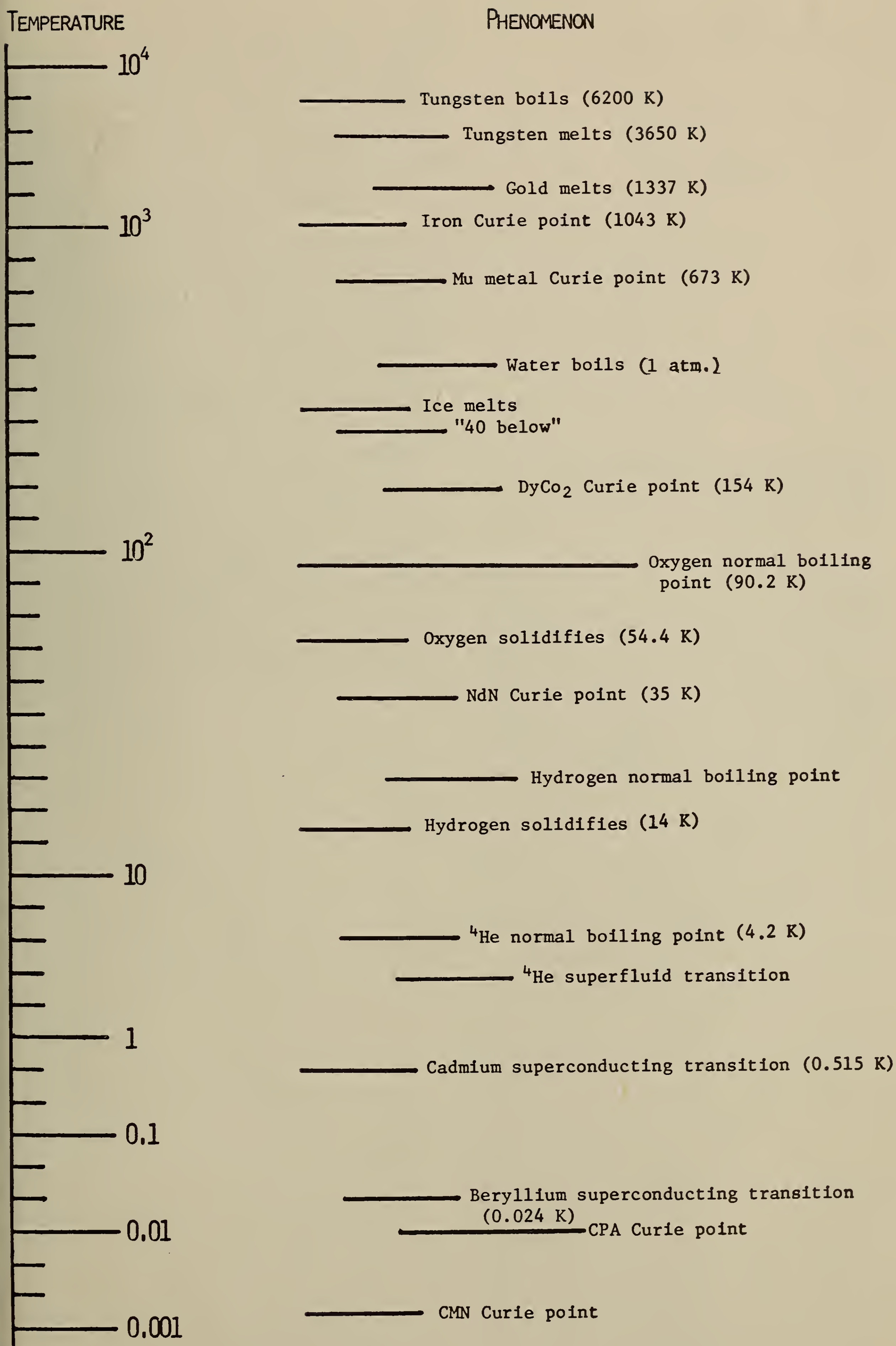

Fig. 1. Temperatures of occurrence of representative physical phenomena.

ENTROPY

$$\Delta S \underset{\text{REVERSIBLE}}{\overset{\text{IRREVERSIBLE}}{\geq}} \frac{\Delta Q}{T}$$

$$T.\Delta S = \Delta Q$$

$$T.\frac{\Delta S}{\Delta T} = \frac{\Delta Q}{\Delta T} = C$$

HEAT CAPACITY

Fig. 2. Definition of entropy, S, and its relationships with heat energy, Q, heat capacity, C, and temperature, T.

vessels, or dewars. It may not be an exaggeration to assert that this device is the single most important technological advance for the field of low temperature physics. The lowest boiling point fluids require double (i.e., nested) dewars for efficient liquefaction and for economical storage. In 1908, helium was first liquefied, at Leiden where Kamerlingh Onnes had for 20 years been building up the world's leading low-temperature laboratory. The boiling point was measured to be 4.2K. At that time only 12 cubic feet of gas were available, painstakingly extracted from monazite sand, and the yield was about one pint of liquid.

Why, one might ask, are low temperature liquids in general important for cryogenic research? The main reasons are 4-fold: by reason of their latent heat of evaporation, they absorb heat from the surroundings at constant temperature and permit one to *maintain* a low temperature; the temperature is readily controllable by controlled pumping; the temperature can be further reduced by pumping; and, finally, the temperature can be measured in terms of the vapor pressure. Subjected to vigorous pumping (forced evaporation), most liquids eventually cool to a point where they become solid, i.e., freeze. But not helium! Kamerlingh Onnes discovered early on that it was still liquid when cooled to 0.7K. Today we know that, unless it is subjected to pressures in excess of 25 atmospheres, helium will remain liquid all the way down to absolute zero.

Metals and Superconductors

Around the turn of this century, it was known that the electrical resistivity of metals decreased with falling temperature. The question remained: What happened at *very* low temperatures? There were various theories: a) the resistivity would fall continuously, b) the resistivity would pass through a minimum and then rise again, c) the resistivity would "flatten out" to a steady value! In 1911 Kamerlingh Onnes undertook to find out. He discovered that the resistance of platinum became constant but, also, that constant value was dependent upon the purity of the specimen. Next, for a metal of the highest then-achievable purity Kamerlingh Onnes selected mer-

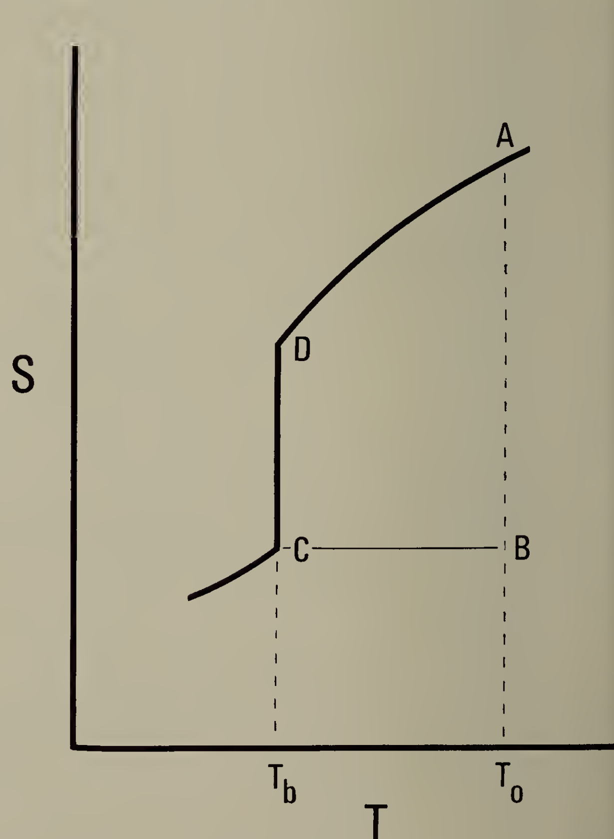

Fig. 3. Entropy vs. temperature curve (schematic) of a hypothetical fluid under constant pressure, say, 1 atmosphere; then T_b is the normal boiling point.

cury. The results were as shown in Fig. 4—at a temperature close to the normal boiling point of helium, the resistance dropped to an immeasurably small value. The phenomenon was at first attributed to a short-circuit developing somewhere in the cumbersome measurement system and much fruitless effort was expended to locate and cure "the fault." Kamerlingh Onnes found this breakdown very disagreeable and, in the Dutch phrase of a Leiden worker[2] in the early years, *zat en zak en as*! With such disbelief was made one of the greatest scientific discoveries of the ages!

Many years later it became possible to demonstrate that this extremely small resistivity was, in fact, zero to a very high order of accuracy. Obviously, metals with zero resistance offer great electrical engineering advantage, but such a property was of great interest to physicists as their thoughts ran on, first to enormous electric currents and then to very intense magnetic fields—all for free, so to speak. This naive hope was soon dashed by the further researches of Kamerlingh Onnes and his associates in the period 1913–1914, into the effect on this *superconductivity* of the size of the current being carried and also of an external magnetic field. In brief, they found that superconductivity was readily suppressed; Silsbee of NBS showed in 1916 that it was the magnetic field at the surface of the conductor (whether generated externally or produced by a current within the conductor) that was the behavior-determining factor.

The lowest value of H which could suppress superconductivity was termed the *critical field*, H_c. This was found to vary from zero at a certain temperature termed the *transition temperature*, T_c, in parabolic fashion to a value H_0 at the absolute zero (by extrapolation, of course). Some representative curves are shown in Fig. 5. In general, a substance exhibiting a high value for T_c has a high H_0, and vice versa. Thus, the values of

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[2] J. A. Kok: Literal translation: . . . sat in sackcloth and ashes. . . .

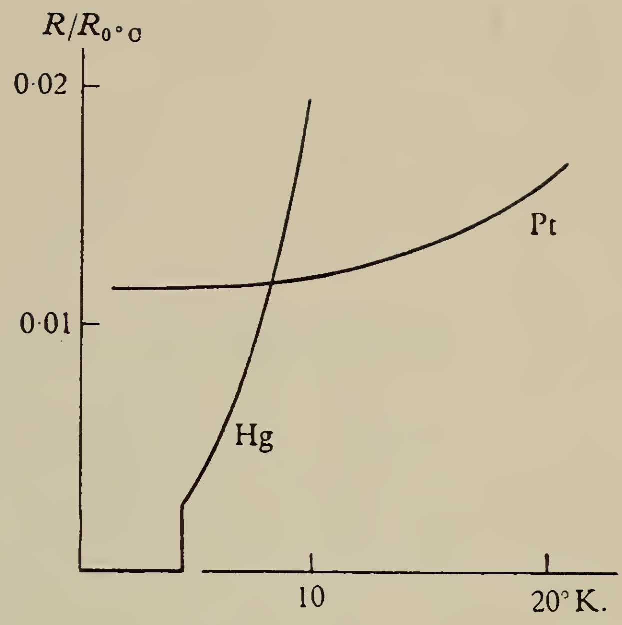

Fig. 4. Resistivity ratio (for a normalization temperature of 0°C) for platinum and for mercury (by Kamerlingh Onnes; after D. Shoenberg, *Superconductivity* [Cambridge University Press, 1952], p. 2).

these quantities are: for lead, 7K and 800 gauss; and for tungsten, 15 mK and 1.2 gauss.

Meissner and Ochsenfeld discovered in 1933 that a metal, upon being cooled to the superconducting state, expels all magnetic flux from itself. This is actually a much more "restrictive" property than would be required simply as a consequence of electrical resistance (or electric field within) being equal to zero. In the terminology of electromagnetic theory, B = 0 rather than merely dB/dt = 0.

As, up to a limit, a magnetic field cannot penetrate a superconductor, the latter may be used to repel a solid magnet (or a coil which is generating a magnetic field). For years, the only consequence of this was the fascinating laboratory demonstration of the "floating magnet" but, as we shall see later, even more striking applications of this property, and of possibly great practical value, are at hand.

With the passage of time, more and more elements were discovered to become superconductors if they were cooled to sufficiently low temperatures. Compounds and alloys are continually being added to the list. Approximately

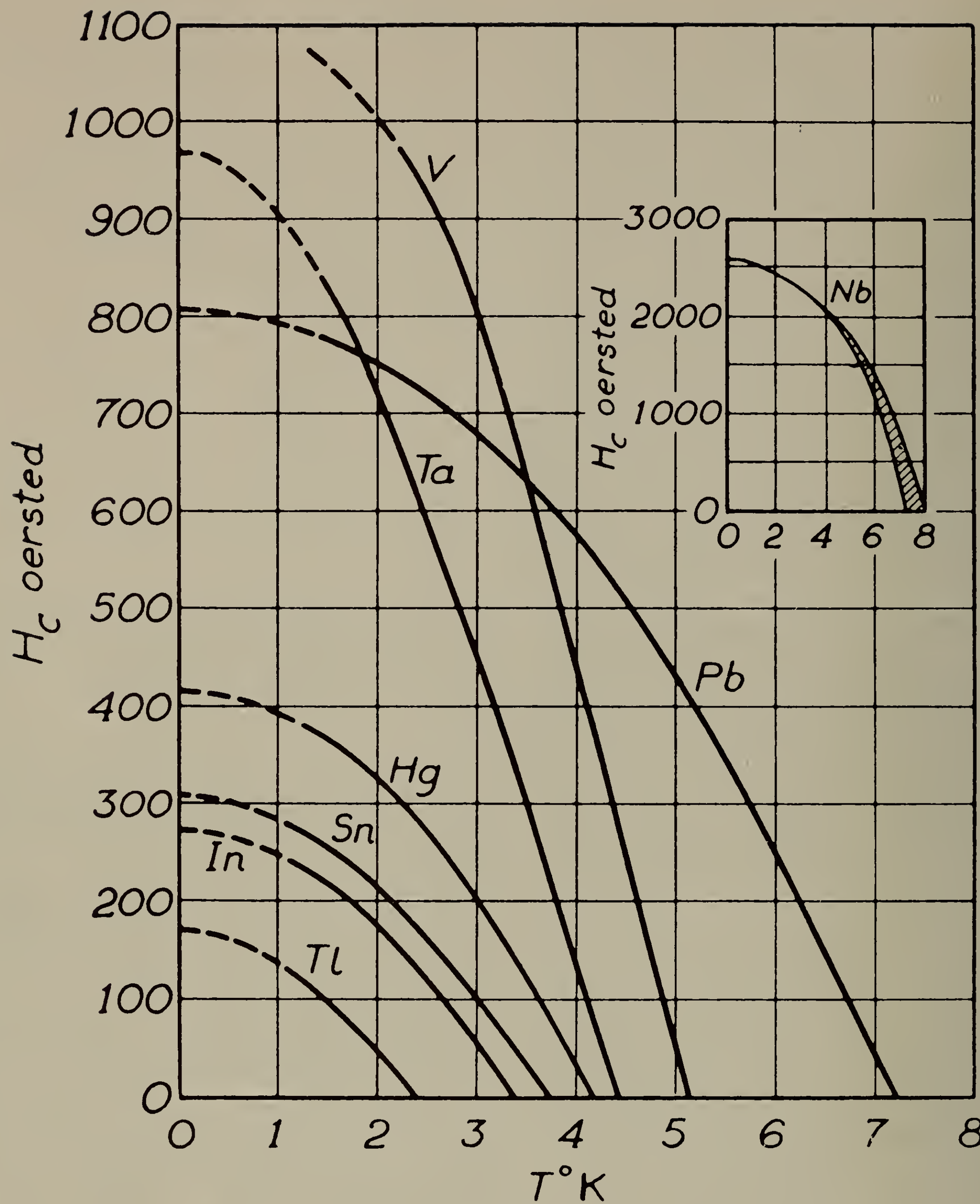

Fig. 5. Temperature dependence of the critical magnetic field, H_c, for selected superconductors (after H. M. Rosenberg, *Low Temperature Solid State Physics* [Clarendon Press, Oxford, 1965], p. 150).

one quarter of the known chemical elements are superconductors at low temperature, although a few of these, it is true, are only so when subjected to very high pressure.

Magnetism

This subject also fascinated the Leiden physicists. Very many substances are *paramagnetic* (i.e. demonstrating magnetic properties when "encouraged" by an applied magnetic field. The latter is unnecessary in the case of the magnetic substances most familiar to the layman, which are termed *ferromagnets*.). The paramagnetism arises because the constituent atoms are little permanent magnets (magnetic "moments" in the technical jargon, symbol μ). An external magnetic field lines up the atomic magnets and the thermal energy opposes this. There ensues a struggle for supremacy between the energies μH and kT. Their ratio, μH/kT, inserted into a simple theory, with mathematics the same as for the molecular gas, went a long way to explaining the early observations, made upon numerous substances. In particular, this theory yielded the Curie Law (magnetic susceptibility inversely proportional to temperature) and did reasonably well in describing the departures therefrom (saturation effects) in high magnetic fields.

Kamerlingh Onnes wanted to probe more deeply, to look for surprises (like superconductivity), and to see how and where the new-fangled quantum theory entered the picture. He also felt that magnetic saturation and superconductivity must have a common basis. A great deal of research on magnetism was carried out in Leiden just before and after World War I. The laboratory fell behind in this particular field for a time in the mid-1920's but had come back to the forefront by 1933, just in time to miss the Nobel Prize! This reference is to the magnetic method of producing temperatures far below those achievable with liquid helium alone, about which we shall now say a few words.

Magnetic Cooling

A cursory thermodynamic treatment of this topic had long been available and Kuenen laid it out in detail in 1922. The essence is as follows:

Starting from the "Maxwell relation"

$$\left(\frac{\partial T}{\partial H}\right)_S = -\left(\frac{\partial M}{\partial S}\right)_H$$

one derives

$$\left(\frac{\partial T}{\partial H}\right)_S = -\frac{T}{C_H}\left(\frac{\partial M}{\partial T}\right)_H$$

$$= \frac{cH}{C_H T}$$

if $M = cH/T$, the Curie Law. Here c is the "Curie constant," C_H is the heat capacity at constant magnetic field and M is the magnetic moment.

The equation enables us to calculate the rise in temperature occasioned by application of a magnetic field under conditions of isolation from the surroundings (constant entropy, S). The reverse of this procedure is the process of *magnetic cooling*. The effect is small except at low temperatures where, as scientists Debye and Giauque independently concluded in 1926, it would constitute a useful process for further refrigeration. Seven years later, the first experimental demonstration was achieved by Giauque himself, pipping Leiden by 2½ weeks!

In the early 1930's, Hitlerism was the direct cause of the establishment of a very productive low temperature laboratory in Oxford—the Clarendon—with the influx of physicists to England from Germany and elsewhere. Much of the work in Oxford, over a long period, was aimed at the refinement and utilization of magnetic cooling. Again, we may advantageously refer to an entropy diagram, Fig. 6. This is similar to the one employed earlier for fluids but now, instead of liquefaction, the "condensation" phenomenon is one of *magnetic ordering*. At a low starting temperature (say, 1K or 2K), T_i, the entropy of a paramagnet, is essentially just that arising from the atomic magnets, the lattice entropy having all but vanished. A magnetic field is applied isothermally, lowering the entropy and bringing the system from point A to point B. The paramagnetic "working substance" is now isolated from the surroundings (which remain at temperature T_i) and the magnetic field is reduced to zero. The system thereupon moves along a line of constant entropy to reach the zero-field curve at point C. The temperature has thus fallen dramatically, to T_f.

The weaker the paramagnetism (smaller μ, few magnetic atoms per unit volume of substance) the lower will be the temperature region in which the S curve falls off, i.e., the lower T_f. There are, however, compensating disadvantages such as reduced heat content (enthalpy), or ability to absorb heat leakage from the surroundings. What magnitude of heat leak can be tolerated? In a typical experimental arrangement, a convenient

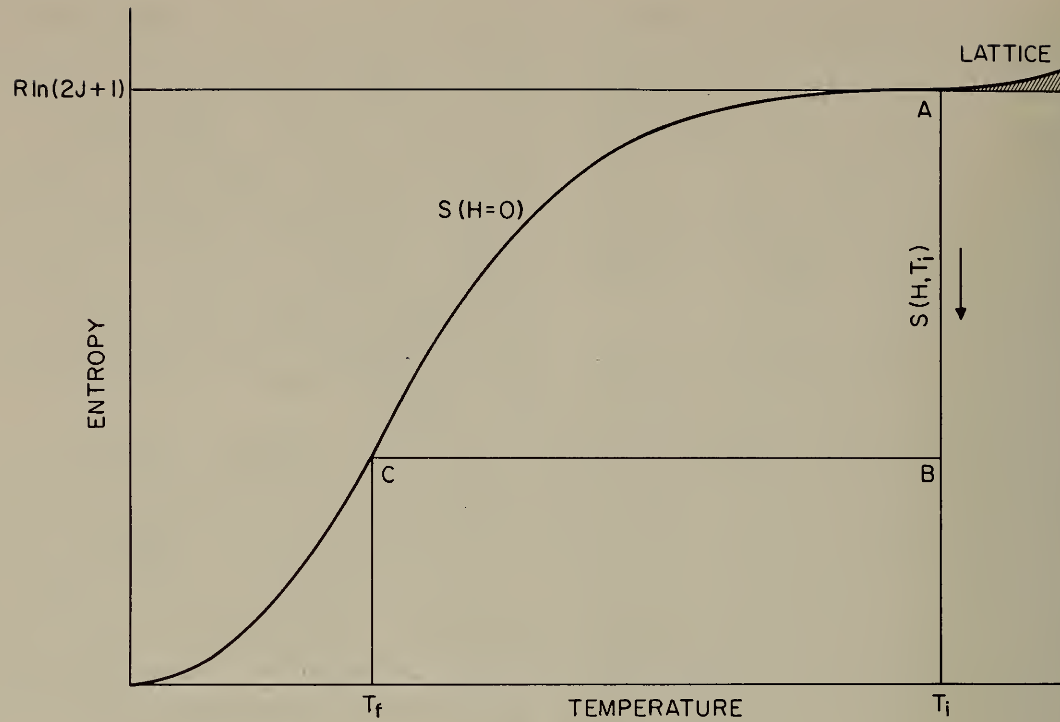

Fig. 6. Entropy vs. temperature curve for a low-temperature paramagnet (schematic).

level is 1 erg per second, enough to bring a cup of water to the boil in 25,000 years or boil it all away in 200,000 years!

The constraint which brings about the fall in entropy at very low temperatures is the interaction between the atomic moments themselves. This may be thought of as an equivalent *molecular field*, h. Considering, again, the system in terms of its entropy, we have

Initial conditions $S_i = f(\mu H/kT_i)$

Final conditions $S_f \approx f(\mu h/kT_f)$

and, equating these (constant entropy process),

$$\frac{\mu H}{kT_i} \approx \frac{\mu h}{kT_f}$$

or

$$\frac{T_f}{T_i} \approx \frac{h}{H}$$

This analysis, which is very approximate, gives one a fair estimate of the T_f to be expected using a starting field, H, up to about 20,000 gauss. Internal molecular fields are usually of the order of 100 gauss and set a practical low temperature limit of about 1 mK.

Nuclear Cooling

Atomic *nuclei* also possess magnetic moments but about 1000 times smaller than the electronic moments we have been discussing up to this point. *Their* interaction is very feeble indeed: a typical "internal field" is of the order of 1 gauss, and the steep entropy drop (Fig. 6) should occur in the neighborhood of 10^{-7} K. Unfortunately, this nuclear magnetism is difficult to utilize effectively. One needs a very intense magnetic field, or a very low initial temperature, T_i, or some compromise combination in order to achieve the requisite large value of H/T.

In practice, these considerations have necessitated employment of a 2-stage process, again reminiscent of the gas liquefaction process. Using such an approach, Kurti and colleagues carried out, at the Clarendon Laboratory in 1956, the first nuclear cooling experiment. The working substance was metallic copper and the copper nuclei were cooled to about 10^{-6} K. Today, twenty years later and after numerous undertakings in several laboratories, it is fair to conclude that major operational difficulties still lie in the way of *applying* such refrigeration to extend scientific investigations.

By now we have lost sight of liquid helium itself, so let us return to say a few words about its own remarkable properties.

Superfluidity

Highly startling properties set in at 2.2K for liquid helium, although 20 years of continual usage followed the first production in 1908 before they began to be noticed! All *appearance* of boiling ceases. The specific heat shows a very sharp maximum. Density and dielectric constant each shows a maximum. The liquid becomes a fantastically good conductor of heat. The liquid exhibits *superfluidity*, i.e., it spreads unrestrainedly over surfaces and cannot be contained in a vessel unless the latter's walls extend into a region of temperature above 2.2K; it will leak without evident impediment through passages as small as *micropores* in special glass (diameter $\sim 10^{-4}$ cm). The surface mobility occurs through what came to be termed the creeping film or Rollin film (after its discoverer). It was this phenomenon which had bedevilled Kamerlingh Onnes' attempts to force-evaporate liquid helium below a temperature of 0.7K. We also now know that solid helium cannot exist at pressures less than 25 bar.

The peculiar properties of liquid helium mentioned above, plus many related unusual phenomena, opened up an enormous area of research which is still under study today in many laboratories throughout the world. It is,however, a difficult subject to say just a little about and I now therefore set it aside.

Nuclear Orientation

This is closely allied to the subject of nuclear cooling. The spatial orientation of nuclei is only the first stage in the latter process, but it is of intrinsic interest if the nuclei are radioactive. The emitting nuclei are like little radio antennae and, similarly, the emissions have directional characteristics, the precise features of which depend on nuclear physics details. At "high" temperatures, all these directional effects are smeared out.

In order to interpret the emission pattern, one needs to know the facts concerning two out of the three of the nuclear physics, the solid state physics, and the temperature. Hence three entirely distinct fields of research are available here. The most famous *nuclear physics* research was the demonstration of parity-nonconservation in beta decay, at NBS in 1956. Also made possible is a very useful *thermometer*, the merits of which are now becoming widely recognized.

Thermometry

Thermometry in low temperature research is important and, as might be anticipated from the remarks just concluded, highly specialized. In addition to the anisotropic-gamma-emission-from-oriented-nuclei thermometer already mentioned, several different kinds are in use, a choice always having to be made to best fit the experimental circumstances. Commonest are the *magnetic thermometer*, employing paramagnetic susceptibility and sometimes (where the approximation suffices) assuming the Curie Law for simplicity; and certain kinds of *resistance thermometer*, both metallic and semiconducting types. And just recently, as the new superconducting measurement technology has made possible greatly enhanced sensitivity for the measurement of (among other properties) magnetic susceptibility, so we may now use the *nuclear magnetic susceptibility* for a temperature indication.

The γ-ray thermometer indicates temperature by our relying on a knowledge of physics and constants of nature; it is therefore a *primary thermometer*. Other low-temperature sensors in this category are the *acoustic* (speed of sound in helium gas) *thermometer*, though this is not suitable for temperatures below 2K, and a low temperature version of the *Johnson noise thermometer* invented by Kamper. These two devices are playing their part in establishing a temperature scale for the cryogenic region but they are not suitable as practical thermometers for use in everyday experimental application.

A part of this scale-development work entails accurately determining the temperature of sharply-defined physical phenomena for use as *thermometric fixed points*, so that reliable temperature references are available for all laboratories which have such a need. To this end, NBS is developing *superconducting fixed points* which make use of the steep fall to zero of the electrical resistance of certain metals, as described above with reference to Kamerlingh Onnes pioneering discovery. At present, pure metal superconductors are available covering the range from 15 mK (tungsten) to 7K (lead) and others are under investigation which, it is hoped, will soon extend the range up to about 20K.

Superconductivity in General

In the late 1940's and early 1950's, theoretical ideas on the origins of superconductivity began to take shape. The early work of Frohlich and Bardeen led in 1957 to the Bardeen-Cooper-Schrieffer (BCS) theory which for the first time gave a satisfactory, microscopic explanation of the basic phenomenon. In the mid-1950's, too, Russian physicists, notably Landau and Ginsburg and, subsequently, Abrikosov and Gorkov, concentrated theoretical efforts on the inhomogeneous features of the superconducting state and thence predicted the possibility of a new class of superconductors.

The theoretically-anticipated "Type II superconductors" appeared on the experimental scene around 1960. Their dominant features are an ability to handle high current densities and to withstand intense magnetic fields. Electromagnets producing fields of 100,000 gauss and more were built and today these are readily available commercially. [Comparable conventional electromagnets have also been built during the last 25 years but these require several megawatts of electric power and vast cooling arrangements. Superconducting magnets, on the other hand, require no continuous power; a circulating current, once initiated, will flow as long as the liquid helium lasts]. Research is being pursued for alloys or compounds which show superconductivity up to even higher temperatures. Transition temperatures higher than 20K have been achieved, but only in systems which, for the moment, have to be classified as laboratory curiosities.

In 1962, Josephson developed the theory of the *weak-link superconducting circuit*, for which work he subsequently received the Nobel prize. Experimentalists almost ignored the subject for a year or two, whereafter took place a very rapid build-up of related research and development of devices in the world's cryogenic laboratories. The basic equation

$$j = j_0 \sin \delta$$

is, with only a modicum of exaggeration, reminiscent of $E = mc^2$ in that it is ludricously simple in appearance, summarizes a wealth of physics impossible to explain in a mere couple of sentences, and leads to quite extraordinary practical consequences. Making an artifact out of the basic idea led to something termed a Superconducting Quantum Interference Device, or SQUID, which is also ludicrously simple in essence. Already, this type of device has been employed to develop a) a new international standard for the volt, b) a new primary low temperature thermometer (above), c) voltage, current, and magnetic field measuring devices of extraordinary sensitivity, not least of which is d) a magnetocardiograph.

This superficial, rapid and perhaps bewildering romp through 100 years of endeavour will not be complete without

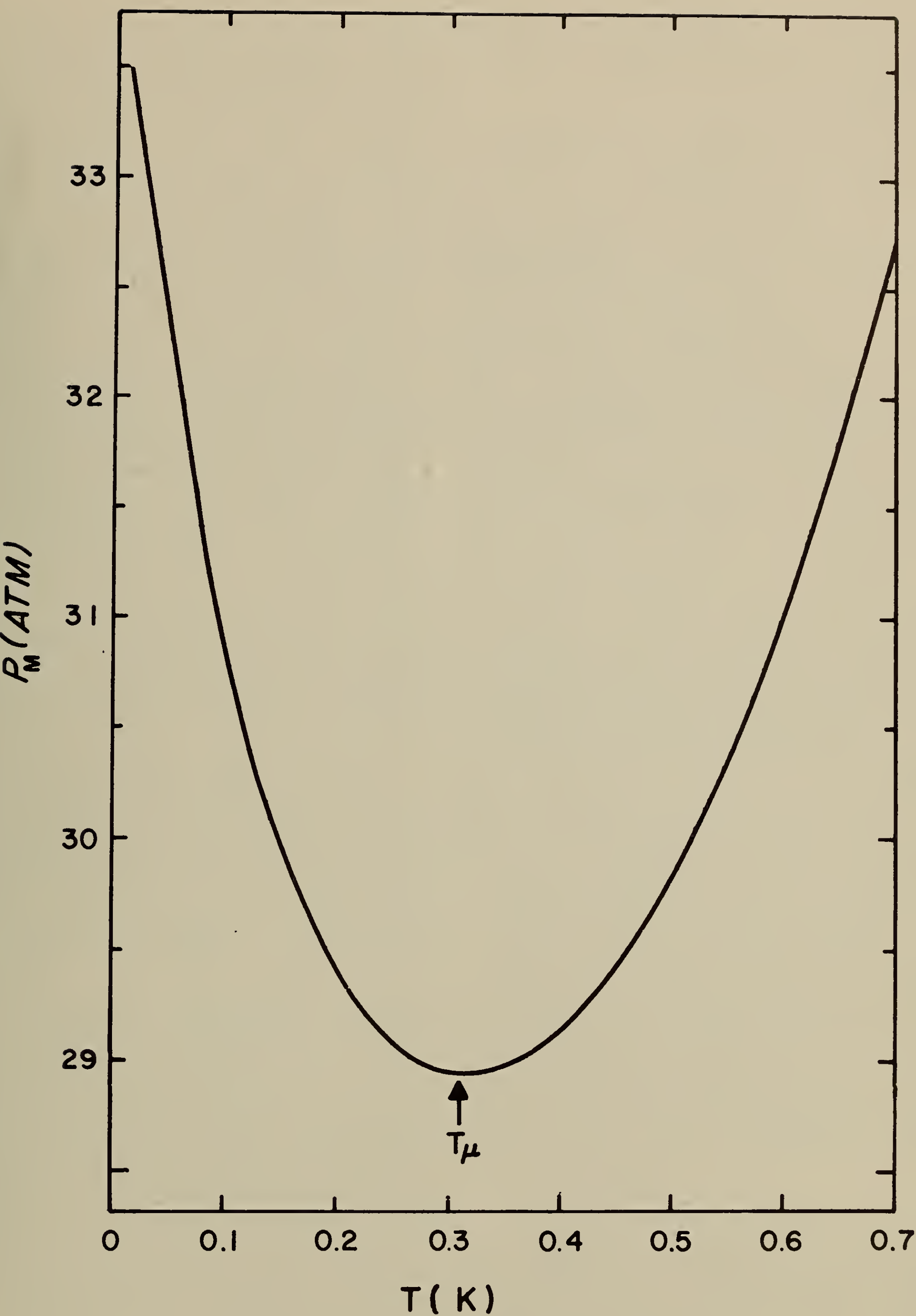

Fig. 7. Melting pressure of ^3He vs. temperature (after R. A. Scribner, M. F. Panczyk, ınd E. D. Adams, *J. Low Temp. Phys. 1,* 313 [1969]).

a word or two about industrial applications and at least a nod in the direction of the light isotope of helium.

^3He

This rare substance, of relative (to ^4He) abundance 10^{-6} in atmospheric helium and 10^{-7} in oil-well helium, has recently become available to researchers in quite generous quantity thanks to the nuclear weapons industry. When compared with its heavier relative, it has quite different bulk properties. These are of great intrinsic interest to the scientist while some, in particular, have considerable practical importance in cryogenic research.

First, when lowered in temperature below 0.3K, the melting curve (Fig. 7) passes through a minimum and rises again. This results in a correspondingly unusual entropy behavior, and one finds that compressing the liquid isentropically causes a *cooling* (called *Pomeranchuk cooling* after the inventor). A temperature of 1 mK has been reached in this way; the method entails compression to 30 atmospheres.

Second, in the liquid state ^3He–^4He mixtures separate into 2 phases at very low temperatures, the one richer in ^3He being uppermost. By forced evaporation one may disturb the equilibrium and cause ^3He atoms to move accross the phase boundary. The process is analogous to volume expansion and the temperature falls, a refrigeration process first envisaged by H. London in 1951 and put into practice by him and co-workers in 1962. From about 1966 on, the pace of development picked up rapidly and soon commercial versions became available. With such equipment the cryophysicist can now have at his disposal continuous refrigeration for the millikelvin region, a most important research tool. Recent advances in this area include the discovery of superfluidity in liquid ^3He at 2 mK (contrast this with the transition in ^4He at 2.2K).

Industrial Developments

A few items, briefly mentioned, will serve to impress one with the giant strides made in cryotechnology over the past century, most of them coming in the last decade or two. Today in the United States, there is a $300M annual production of liquid oxygen, 50% for the steel industry and 20% in the chemical industry. Annual sales of liquid nitrogen are about $150M with more than one-third used for freezing food. By 1985, about 10% of our natural gas will be imported in the liquid state. This activity requires the provision of very large storage tanks, some 10 stories high! Liquid hydrogen is used as a fuel in space rockets (it is also being tested for an alternative to gasoline in automobiles) and is stored in containers of 1 million gallons capacity. The U.S. Navy is building 3000 H.P. superconductive motors and generators and has design work under way for 30,000 H.P. Superconductive cable for power transmission is being developed, and Japan has a superconductive motor-driven and levitated train.

Helium is even *exported* today in the liquid state, 6000 gallons at a time by ocean transport. This brings me to end on a pessimistic note: for decades helium was just allowed to escape into the atmosphere; then for a time it was separated from the natural gas and restored underground; a few years ago this federally-sponsored program was terminated in an economy move. It is therefore possible that just as this country is prepared to move forward into a major national exploitation of low temperature technology we shall reap our reward for the profligate waste of this precious, irreplaceable resource that has been going on for many decades, i.e., we shall run out of helium. But that is another entire lecture!

Polynomial Regression Analysis Using a Principal Components Rotation

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ABSTRACT

Fitting nonlinear relationships using a polynomial calibrated with multiple regression usually leads to irrational coefficients. However, by using a principal components rotation of the correlation matrix prior to regression, a set of rational coefficients may be obtained for polynomials. An analysis of daily pan evaporation and mean air temperature is used to illustrate the value of fitting polynomials using a principal components analysis.

Regression techniques are used for prediction in engineering and the physical sciences as well as in the behavioral sciences. While linear regression is the most frequently used technique, bivariate relationships that exhibit nonlinear trends are not uncommon. For nonlinear relationships, the least squares criterion is frequently used to obtain a polynomial equation to represent the relationship between the two random variables.

The method of regression that is used in polynomial analyses makes the critical assumption that the variables used for prediction are independent. In polynomial analyses the predictor (independent) variable and powers of it are used as the predictors. But the predictor variable and its powers are never independent and they are usually very highly correlated. This violates the basic assumption of the least squares criterion and often results in irrational coefficients in the polynomial equation. The irrational coefficients often result in irrational predictions, especially for values of the predictor variable that are outside the range of the data used for calibrating the polynomial.

This paper presents a technique that circumvents the intercorrelation problem without an appreciable loss in accuracy of prediction. The calibration algorithm is based on a principal components rotation of the correlation matrix. By circumventing the intercorrelation problem, a polynomial with rational coefficients can be obtained.

Eigenstructure Analysis

The least squares solution for polynomial analysis requires the inversion of the correlation matrix. When high intercorrelation exists between the predictor variable and powers of it, then the correlation matrix may be singular or near-singular. In such cases, the accumulation of round-off error becomes appreciable and irrational coefficients are the result.

Principal components analysis provides an alternative solution. By rotating the correlation matrix prior to using the least squares criterion, a set of orthogonal vectors that can be used to obtain the regression coefficients are provided. The orthogonal vectors are obtained using a principal components analysis of the correlation matrix.

A principal components analysis of a correlation matrix R is based on the solution of the simultaneous equations, expressed in matrix form as:

$$RV = \lambda V \tag{1}$$

where R is an (n × n) matrix of bivariate correlation coefficients, V is a (n × 1) vector of unknowns, and λ is a scalar. A solution of equation 1 provides values for the constant λ, which is called the eigenvalue, and the vector V, which is the eigenvector. For a matrix R of rank m ($m \leq n$) there will be m solutions to equation 1. The resulting eigenvalues and eigenvectors represent the eigenstructure of the correlation matrix.

While a geometric interpretation of the eigenstructure analysis is informative (Cooley and Lohnes, 1971), it may suffice here to provide interpretations of the eigenvalues. The eigenvalue divided by the rank of the matrix represents the proportion of variance in the correlation matrix that is extracted by the corresponding principal component. Because not all of the variance is meaningful (i.e., a portion of the variance represents random error), not all of the eigenvalues and eigenvectors are statistically significant. A regression analysis that is based only on the significant eigenvalues and eigenvectors will usually produce a rational prediction model. By eliminating the unwanted random or error variance, the coefficients will remain rational.

While many criteria have been proposed for identifying the significant eigenvalues, Kaiser's rule-of-thumb (Kaiser, 1960) is generally recognized as the most reliable. Kaiser's rule states that for samples of small or moderate size, all eigenvalues greater than one are statistically significant.

Polynomial Analysis with Principal Components

A computer program was developed that permitted the calibration of polynomials using a regression based on a principal components analysis of the correlation matrix. While the criterion variable is regressed on a linear function of the principal components rather than the predictor variable and its powers, the resulting prediction equation does not require the evaluation of the eigenstructure when determining a predicted value of the criterion variable.

The solution is an iterative process in which a prediction equation is calibrated for the analysis based on the sequential addition of eigenvalues. And because some of the variation in the correlation matrix is considered to be error variation, the total explained variation (i.e., the square of the correlation coefficient) for the principal components model may be smaller than that explained by the polynomial model calibrated using the standard regression analysis technique.

The method will be illustrated using a data set that consists of the daily pan evaporation (inches/day) and the average daily air temperature (°F). Three hundred fifty-four observations were obtained from a site near Tifton, Ga. The following linear regression equation was derived:

$$E_1 = -.114 + 0.00383T \qquad (2)$$

where E is the pan evaporation in inches per day, and T is the daily mean air temperature (°F). The equation provided a correlation coefficient of 0.581. Table 1 gives predicted values of evaporation for selected values of T. While the true values are not known, the estimate for a temperature of 100°F was considered to be about 10% low; otherwise, the model provides reasonably good estimates.

Using the multiple regression technique with temperature and its powers as predictor variables, the following quadratic and cubic polynomials were evaluated:

$$E_2 = 0.425 - 0.0142T + .000143T^2 \qquad (3)$$

and

$$E_3 = -0.239 + 0.0205T - 0.000439T^2 + 0.00000314T^3 \qquad (4)$$

Equations 3 and 4 resulted in correlation coefficients of 0.648 and 0.654, respectively. These represent an increase in the explained variation of approximately 8% and 9%, respectively, in comparison with the linear model. The computed values of Table 1 and the graphical representation of the equations in Fig. 1 indicate that the models are not rational.

Table 1.—Predicted Values of Pan Evaporation for Selected Air Temperatures.

	Predicted pan evaporation (inches/day) with:			
Temperature (°F)	Linear model	Quadratic model	Cubic model	Principal components model
32	.009	.117	.070	.025
50	.078	.073	.081	.075
75	.173	.164	.154	.174
100	.269	.435	.561	.317

Both models have irrational values at temperatures of 32° F and at 100° F. Furthermore, the quadratic equation shows a noticeable downward trend that extends even above temperatures of 50° F, which is within the range of the data used for calibrating the models. Thus, the nonlinear models are not rational when calibrated using polynomial fitting with multiple regression, which is the traditional method of analysis.

A cubic equation was calibrated using the polynomial analysis with a principal components rotation of the correlation matrix. The eigenstructure analysis resulted in 3 eigenvalues, with the first eigenvalue equal to 2.981 and each of the other 2 eigenvalues less than 0.015. Thus, according to Kaiser's rule-of-thumb there is only 1 significant eigenvalue and eigenvector. The cubic polynomial resulting from a regression on this eigenvector produced the following equation:

$$E_4 = -0.0324 + 0.00134T + 0.0000106T^2 + 0.00000011T^3 \qquad (5)$$

A correlation coefficient of 0.607 resulted. This is noticeably larger than that for the linear model and only slightly less than those for the quadratic and cubic equations derived from multiple regression. However, equation 5 provides more rational predictions than any of the equations derived using the traditional method of analysis.

While only 1 eigenvalue was found to be significant, this represented 99.4% (2.981/3) of the variation in the correlation matrix. The remaining 0.6% of the variation is considered to be error variation. But by including this in the analysis, the irrational model of equation 4 results. By eliminating this error variation, equation 5 produced more rational estimates.

Discussion and Conclusions

Nonlinear trends are often identified in data sets from many physical systems. Such nonlinearity may result because of nonlinear processes that govern the response of the system or because of the large variation in the data used to establish the relationship and the change in the importance of the various processes within the system. Many researchers have attempted to circumvent this nonlinearity by transforming the data; a logarithmic transformation is very common. However,

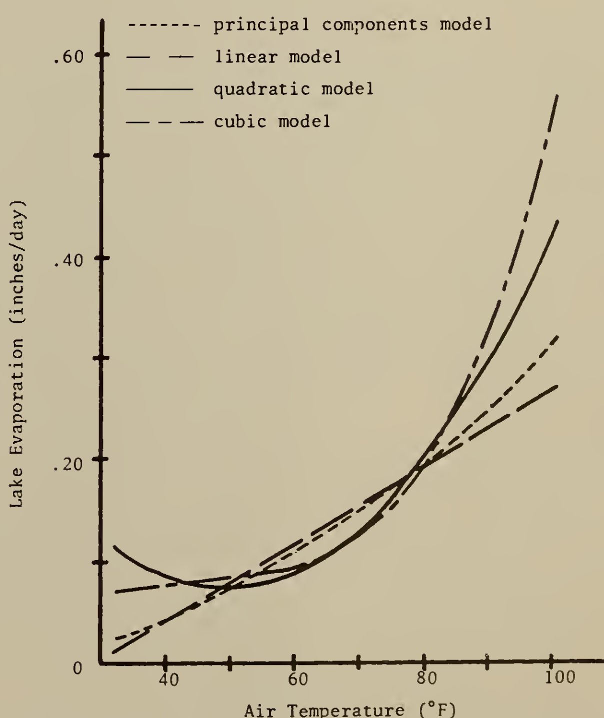

Fig. 1.—Comparison of prediction models.

data transformations results in the violation of theoretical considerations that form the basis for the regression technique. Specifically, when data are transformed the distribution of the residuals is rarely normal. Thus, polynomial fitting using a principal components rotation provides an alternative to data transformations.

Model selection from among alternatives is often based on statistical criteria; for example, the model producing the highest correlation coefficient is often selected. While statistical criteria, such as the goodness-of-fit criteria of the correlation coefficient and the standard error of estimate, are useful indices of the fit between observed and predicted values, they may not be a reliable index for the accuracy of future predictions with the model, especially when the sample size is small. Thus, criteria other than statistical goodness-of-fit criteria are just as important, and probably more important. The rationality of the coefficients and the distribution of the errors are two criteria that should always be assessed when developing a model. The regression technique that includes a principal component rotation appears to provide rational coefficients for N^{th} order polynomials and thus is a valid alternative to the frequently used multiple regression technique for polynomial analyses.

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Microcracking of Concrete

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ABSTRACT

The major objective of this investigation was to directly observe the formation and/or propagation of microcracks in concrete both before and after application of compressive stress fields.

Concrete, under compression, fails when microcracks have propagated to the extent that the concrete will not support the applied loads. Many investigators have implied that the failure mechanism of concrete is related to internal microcracking. However, due to the limitations in the techniques employed, the detection of microcracks was somewhat uncertain.

The scanning electron microscope (SEM) was chosen as the viewing apparatus because of its distinct advantages to directly observe the formation and/or propagation of microcracks.

Microcracks were found to exist in concrete prior to application of compressive stress fields in the form of shrinkage microcracks (initial bond microcracks). As the compressive stress field is increased, these microcracks wide and propagate until failure occurs.

Many investigators have implied that the failure mechanism of concrete is associated with internal microcracking (1–6). The formation and propagation of such microcracks have been studied indirectly by sonic velocity, acoustic methods, and by the observation of macrocracks on the surface of the models. Robinson (7) and Hsu *et al.* (8) have directly observed the formation and propagation of microcracks by x-ray analysis. Due to the limitations in the technique employed, the detection of microcracks was somewhat uncertain.

In addition, Hsu *et al.* used a light microscope at 40× magnification to verify the results of the x-ray analysis. They examined cross sections of concrete (0.15 inches thick) both before and after application of compressive stress fields. In those concrete models which were examined after application of compressive stress fields, the concrete was sliced perpendicular to the direction of the applied load. Prior to slicing and examination of the concrete models, they were subjected to various compressive stress fields and the loads were subsequently removed.

According to Hsu *et al.*, 3 types of microcracks were identified: bond, matrix, and aggregate microcracks. Further, bond microcracks (microcracks between the cement mortar matrix and aggregate particles) exist in the form of shrinkage microcracks prior to application of compressive stress fields. These initial microcracks begin to propagate at approximately 30–40% of the ultimate strength. The stress-strain curve deviates from linearity at this point, and there is an increase in the lateral expansion of the concrete. Matrix microcracks (microcracks in the cement mortar matrix) are formed by propagating bond microcracks at about 70–90% of the ultimate strength. Aggregate microcracks occur just before failure.

Hansen (9), in an attempt to verify the conclusions of Hsu *et al.*, disagreed on some aspects of their findings. Hansen also tried to observe microcracks in concrete both before and after application of compressive stress fields, but the compressive stress fields were not removed prior to observation. Hansen applied a purely axial compressive stress field to the concrete models and observed (using a light microscope at 50× magnification) the formation and propagation of surface microcracks. Under a purely axial load, microcracks are believed to originate in the center of the concrete and propagate to the outer surface. Hansen, however, did not find bond microcracks in the form of shrinkage microcracks prior to application of compressive stress fields under magnifications as high as 1000× with the light microscope. Hansen discovered that bond microcracks (under a magnification of 50×) occurred at about 45% of the ultimate strength unlike the 30–40% figure found by Hsu *et al.* He agreed that matrix microcracks occur between 70 and 90% of the ultimate strength, and that aggregate microcracks occur just before failure.

It is apparent from the differences in the data received and the techniques employed by Hsu *et al.* and Hansen that further basic research is needed in the field of concrete microcracking. A better understanding of the failure mechanism of concrete (at the microlevel) may provide a more knowledgeable understanding of the engineering properties of concrete, possibly leading to developments for improving these properties and subsequently improved use of concrete materials.

The major objective of this investigation was to observe directly the formation and/or propagation of microcracks in concrete both before and after the application of compressive stress fields. The compressive stress fields selected were 15, 45, and 75% of the ultimate strength of concrete.

It was not known what effect, if any, aggregate shape would have on the formation and/or propagation of microcracks in concrete. As a result, 2 distinct concrete models were used with the following parameters (Table 1).

Design of Experimental Investigation

It was decided to use the scanning electron microscope (SEM), model AMR 900 as the viewing apparatus (to observe microcracks in concrete directly) because of its unique capabilities and its distinct advantages over other viewing apparatus such as the light microscope and the transmission electron microscope. With the SEM it is possible to scan a 1 in^2 area, to magnify the same area 100,000×, and to obtain a relatively clear, sharp photograph.

Table 1.—Parameters considered.

Parameters	Model 1	Model 2
Ultimate Strength	3000 lbs/in^2 (211 kg/cm^2)	3000 lbs/in^2 (211 kg/cm^2)
Coarse Aggregate Shape	Rounded	Angular
Fine Aggregate Shape	Rounded	Angular
Top Size of Coarse Aggregate	0.50 in. (1.27 cm)	0.50 in. (1.27 cm)
Curing Time	28 days	28 days
Curing Temperature	70°F (21°C)	70°F (21°C)
Curing Relative Humidity	29 ± 2%	98 ± 2%
Number of Samples	4	4

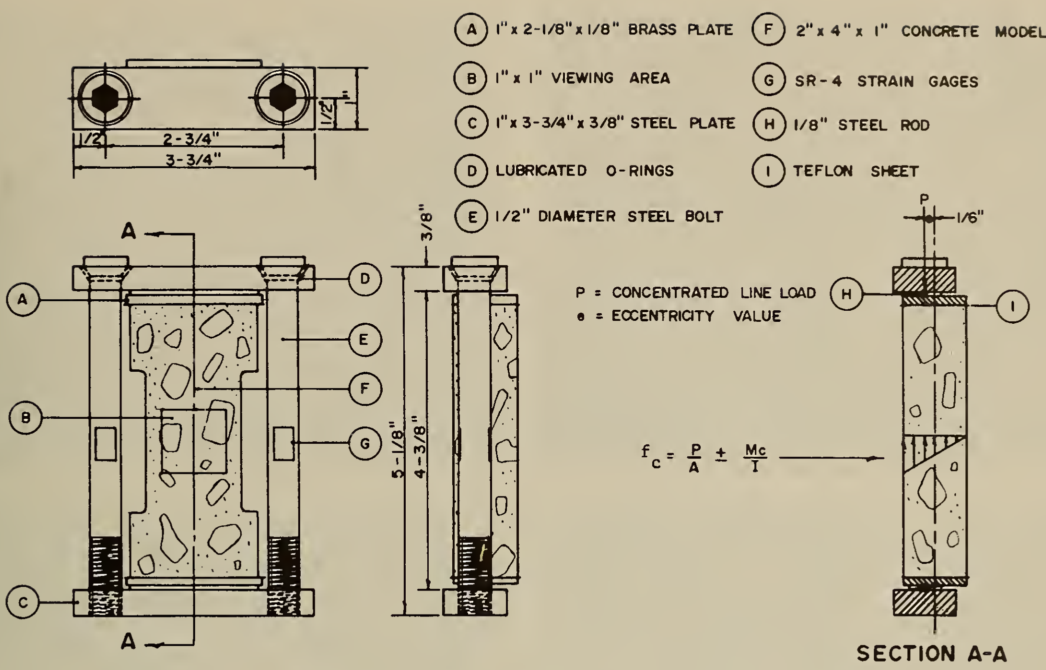


Fig. 1. Loading apparatus.

Two SEM limitations were encountered in this type of investigation. First, there was only a 5″ × 7″ × 1-½″ (12.7 cm. × 17.8 cm. × 3.8 cm.) usable space in the high-vacuum (10^{-6} torr) chamber. Since the major objective of this investigation was to observe microcracks directly in concrete under application of compressive stress fields, a loading apparatus (Fig. 1) had to be designed which would allow for the maximum size model possible (Fig. 2) and still be placed in the SEM vacuum-chamber in its entirety. The loading apparatus had to be designed to allow for the direct observation of microcracks when they form and/or propagate; this necessitated the eccentric loading of the concrete models. Thus, the size of the SEM vacuum-chamber controlled the size of the loading apparatus as well as the size of the concrete models.

The second limitation of the SEM was that in a high vacuum the concrete models must be relatively free of moisture; otherwise, due to the moisture in the concrete models, optimum operation cannot be reached. The models may contain molecular moisture; any moisture in excess of this amount cannot be tolerated. This limitation required developing a delicate 4-cycle drying process that would not include microcracking. The 4-cycle drying process consisted of: air drying, desiccator drying (with silica gel as the desicant), vacuum-desiccator drying, and oven drying. In each cycle the models were dried to constant weight (as determined by daily weighing) before advancing to the next cycle. The entire process lasted approximately 25 days. To

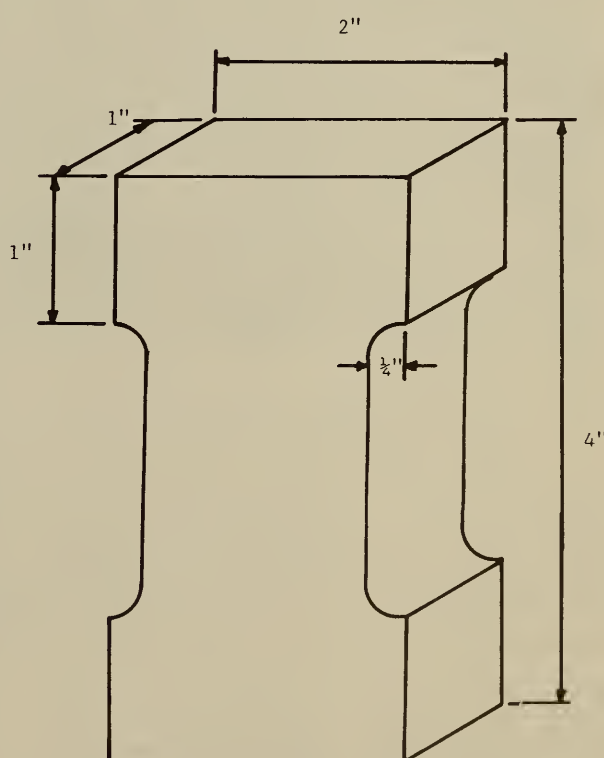
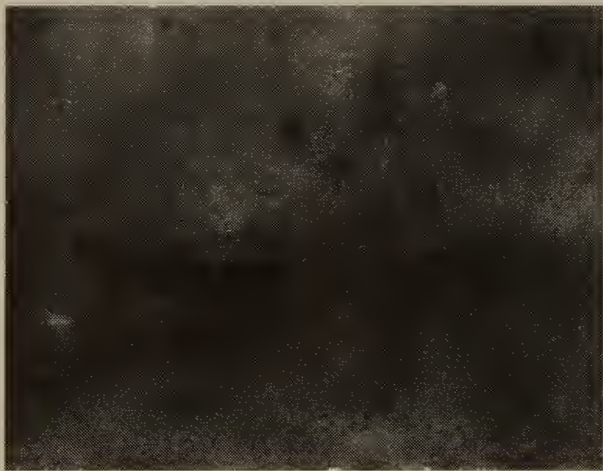
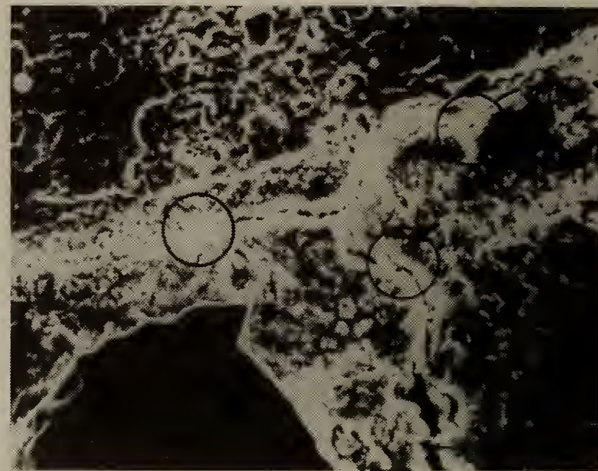
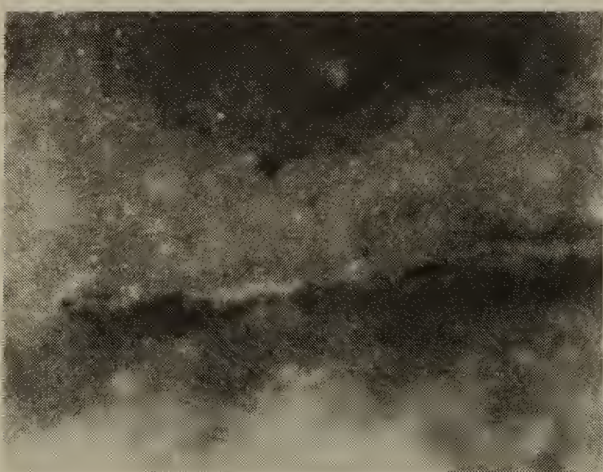
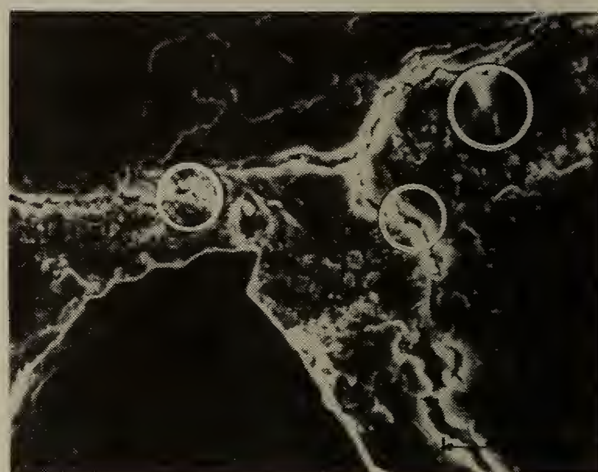


Fig. 2. Concrete shape and size (Model).









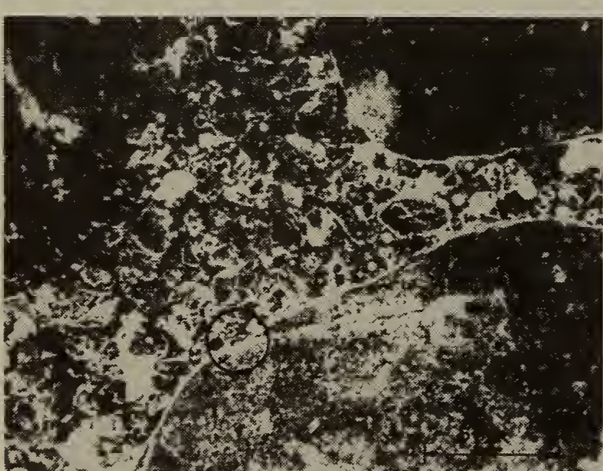
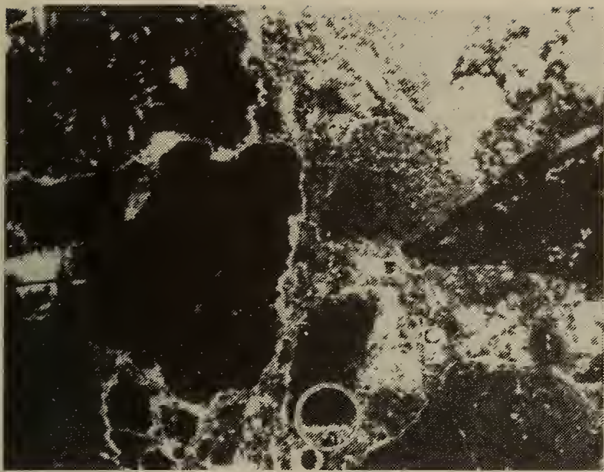


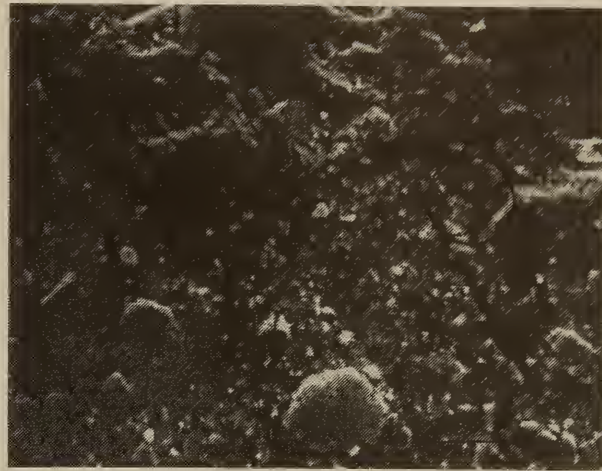
Fig. 3 (top left), shrinkage microcrack prior to application of 4-cycle drying process.
Fig. 4 (middle left), shrinkage microcrack after application of 4-cycle drying process.
Fig. 5 (bottom left), scanning area of the concrete model containing rounded aggregate.
Fig. 6 (top right), scanning area shown in Fig. 4 magnified to illustrate existence of shrinkage microcracks in concrete containing rounded aggregate.
Fig. 7 (middle right), microcracks in concrete containing rounded aggregate under application of a compressive stress field of 15% of the ultimate strength.
Fig. 8 (bottom right), microcracks in concrete containing rounded aggregate under application of a compressive stress field of 45% of the ultimate strength.

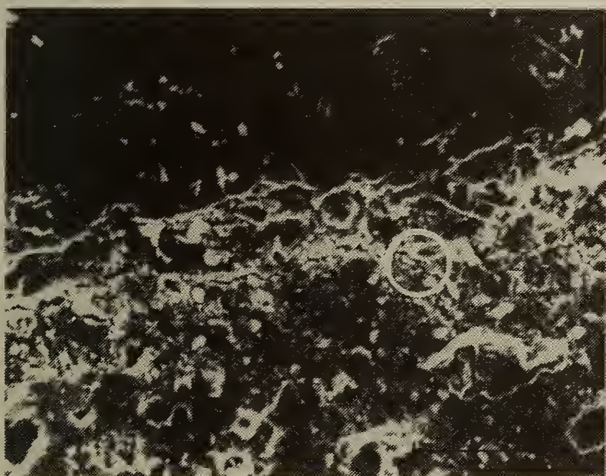
confirm the fact that the drying process would not induce microcracking, a procedure was established with the use of the light microscope.

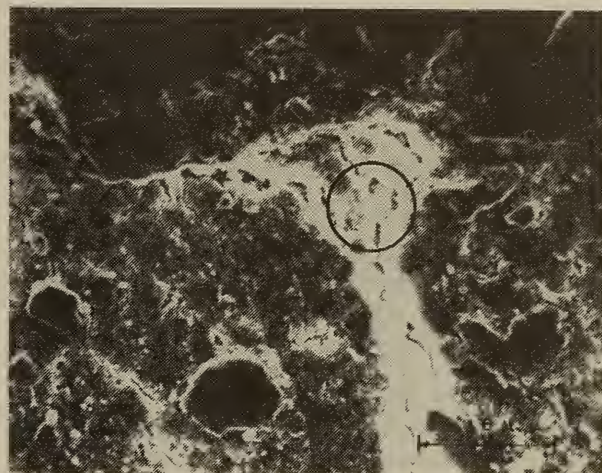
Results

Shrinkage Microcracks.—The results indicate the existence of shrinkage microcracks both in concrete containing









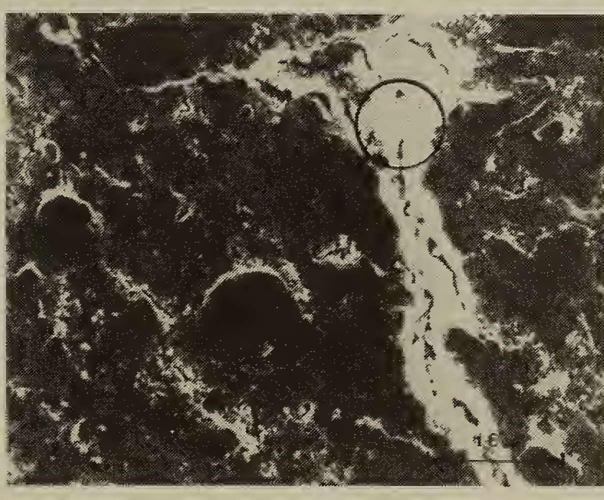


Fig. 9 (top left), scanning area of the concrete model containing angular aggregate.

Fig. 10 (middle left), scanning area shown in Fig. 8 magnified to illustrate existence of shrinkage microcracks in concrete containing angular aggregate.

Fig. 11 (top right), microcracks in concrete containing angular aggregate under application of a compressive stress field of 15% of the ultimate strength.

Fig. 12 (middle right), microcracks in concrete containing angular aggregate under application of a compressive stress field of 45% of the ultimate strength.

Fig. 13 (bottom), microcracks in concrete containing angular aggregate under application of a compressive stress field of 75% of the ultimate strength.

rounded aggregate and in concrete containing angular aggregate. Neither the delicate 4-cycle drying process nor the SEM in obtaining a high-vacuum created, propagated, or widened these shrinkage microcracks. Many shrinkage microcracks were encountered in the concrete models, though only a few photographs will be shown. Fig. 3, obtained with the light microscope at an original magnification of 200×, is a typical shrinkage microcrack, in concrete containing rounded aggregate, prior to the application of the 4-cycle drying process. Similar shrinkage microcracks were encountered in concrete containing angular aggregate. These shrinkage microcracks are known as initial bond microcracks. It was concluded from Fig. 3 and similar photographs that microcracks exist in concrete prior to application of compressive stress fields.

Fig. 4, also obtained with the light microscope at an original magnification of 200×, is the same shrinkage microcrack shown in Fig. 3, but after the 4-cycle drying process. In a comparison of Figs. 3 and 4, there do not appear to be any differences, nor was there any change in the existing microcracks or development of new ones. As a result, it was concluded that the 4-cycle drying process did not create, propagate, or widen shrinkage microcracks.

Microcracks in Concrete Containing Rounded Aggregate.—Figs. 5 through 8 are photographs of microcracks obtained with the SEM in concrete containing rounded aggregate both before and after application of compressive stress fields. Fig. 5 is a photograph of the scanning area of the concrete model prior to application of compressive stress fields: shrinkage microcracks are not obvious at this magnification. By magnifying and photographing the encircled area, Fig. 6 is obtained.

It is apparent from viewing Fig. 6 that shrinkage microcracks exist in concrete containing rounded aggregate. This shrinkage microcrack is not merely an initial bond microcrack (as described by Hsu *et al.*) but has matrix microcrack extensions. The average width of the microcrack in Fig. 6 is approximately 3 microns.

Applying a compressive stress field of 15% of the ultimate strength, a value within the straight line portion of the stress-strain curve, and viewing the encircled areas of Fig. 6 results in Fig. 7. It would appear that the microcracks have doubled in size (6 microns) and the matrix microcrack in the upper right hand corner of Fig. 6 has propagated.

By increasing the compressive stress field further to 45% of the ultimate strength and viewing the same area as in Figs. 6 and 7 results in Fig. 8. The microcracks have widened considerably, approximately 8 times (21 microns) their original width.

Microcracks in Concrete Containing Angular Aggregate.—Figs. 9 through 13 are photographs of microcracks, observed with the SEM, in concrete containing augular aggregate both before and after application of compressive stress fields. Fig. 9 is a photograph of the scanning area of the concrete model prior to application of compressive stress fields. Again shrinkage microcracks are not obvious at such a low magnification. However, if the encircled area is magnified and photographed, Fig. 10 results.

It is obvious, from viewing Fig. 10, that shrinkage microcracks exist in concrete containing angular aggregate. This shrinkage microcrack is not merely an initial bond microcrack (as described by Hsu *et al.*) but deviates from the aggregate-matrix interface (bond) into the matrix. The average width of the microcrack in Fig. 10 is approximately 2 microns.

Applying a compressive stress field of 15% of the ultimate strength and viewing the encircled area of Fig. 10 yields Fig. 11. The bond portion of the microcrack has increased in width approximately 5 times and the matrix microcrack extensions have become much more pronounced.

Increasing the compressive stress field to 45% of the ultimate strength and viewing the same encircled area as in Figs. 10 and 11 results in Fig. 12. At this point, matrix microcracks begin to bridge bond microcracks with no noticeable increase in width, and the matrix microcracks become much more pronounced.

With a further increase of the compressive stress field to 75% of the ultimate strength, Fig. 13 results. There appears to have been a shifting of the aggregate particle and a widening of the microcrack.

Discussion of the Results

Shrinkage Microcracks.—This investigation supports the results of Hsu, Slate, Sturman, and Winter in their study of shrinkage microcracks: microcracks exist in concrete prior to application of compressive stress fields. The results further show that shrinkage microcracks exist both in concrete containing rounded aggregate and in concrete containing angular aggregate. These shrinkage microcracks were not just initial bond microcrack extensions at right angles. Sturman (10) suggested that shrinkage microcracks may be formed by variety of processes, including carbonation shrinkage, hydration shrinkage, segregation due to settlement, and drying shrinkage. It is hypothesized that the shrinkage microcracks encountered in this investigation resulted from segregation due to settlement and, to some extent, hydration shrinkage.

Carbonation shrinkage occurs when any cement compound is stored in air and decomposed by carbon dioxide. The portland cement used in this investigation was of good quality and had just been manufactured and purchased. It had very little time to be exposed to air. Therefore, it does not seem likely that shrinkage microcracks were formed by carbonation shrinkage.

Hydration shrinkage occurs when the primary cement-paste volume decreases its volume during hydration, resulting in the formation of microcracks. This is said to be controlled by expansive cements. Since Type III-A cement (used in this investigation) is not an expansive cement, microcracks are possible.

According to Sturman, the influence of segregation due to settlement on the formation of microcracks may be analyzed by applying Stoke's law to the viscous material first formed when sand, cement, and water are mixed to form mortar. Stokes found that for very small solid particles suspended in a viscous fluid, the steady state or terminal velocity acquired by the larger and denser particles is greater than that of the smaller, less dense particles. Thus, in the sand-cement-water mixture the large sand particles will settle first, the fines next, and the extremely fine, flocculated particles last. This leads to a condition in which there is, adjacent to the aggregate, a thin film of fluid with an extremely high water to solids ratio. Eventually this water is absorbed by the adjoining cement paste which hydrates continuously and a thin space is left at this point on the aggregate. When this sedimentation occurs at the exposed horizontal surface of freshly poured concrete, it is referred to as bleeding. This phenomenon is likely the cause of shrinkage microcracks in concrete and is probably the major cause of shrinkage microcracks in this investigation.

The final possibility is drying shrinkage. Drying shrinkage occurs in plastic concrete if the rate of evaporation exceeds 0.1 lbs/ft.^{2} of surface area/hr. In other words, hydrostatic tension is present, resulting in shrinkage microcracks. If the concrete were cured in a water-saturated atmosphere, as it was in this investigation, shrinkage microcracks do not develop. Therefore, this possibility was ruled out.

It was not known why Hansen did not encounter shrinkage microcracks, because there was no information available as to the concrete materials and curing procedures used.

Concrete Containing Rounded Aggregate and Concrete Containing Angular Aggregate.—Hsu *et al.* stated that bond microcracks (which exist prior to the application of compressive stress fields) propagated at 30–40% of the ultimate strength. Hansen found that bond microcracks did not originate until 45% of the ultimate strength. In this investigation, bond microcracks (which exist prior to the application of compressive stress fields) did not propagate at all but merely widened under increasing compressive stress fields. The propagation of microcracks occurred only to the matrix extensions.

Both Hsu *et al.* and Hansen further agree that matrix microcracks occurred between 70 and 90% of the ultimate strength. In this investigation, matrix microcracks were extensions of bond microcracks and existed prior to application of compressive stress fields. These matrix microcracks were at right angles to the bond microcracks. Under increasing compressive stress fields (as low as 15% of the ultimate strength) matrix microcracks widen and propagate to the point that they begin to bridge bond microcracks.

This investigation further shows that at 45% of the ultimate strength the bridging of bond microcracks is about completed. At 75% of the ultimate strength the matrix microcracks start to bridge one another.

The differences between the results obtained in this investigation and those of previous investigations are easily explained. The depth of field and scanning ability are the 2 features that make the SEM particularly well suited for fractography. Its depth of field is many times greater than that provided by the light microscope (such as that used by Hsu *et al.* and Hansen) for equivalent magnifications. This feature permits both the peaks and valleys normally encountered on rough fractured surfaces to be imaged in focus, even at relatively high magnifications. The light microscope used in previous investigations had poor depth of field at 40X and 50X magnification. This poor depth made it difficult to distinguish between actual microcracks in the matrix and very porous mortar. Even the use of the light microscope in this investigation presented doubt as to the existence of an actual microcrack. At lower compressive stress fields Hsu *et al.* and Hansen may have mistaken the microcracks to be very porous mortar (since the microcracks were only 3 or 4 microns wide) and only when the microcracks reached a proportional size could a difference be made. This may account in part for the higher values received by Hsu *et al.* and Hansen in their investigation of matrix microcracks.

In addition, Hsu *et al.* removed the compressive stress fields prior to observation of microcracks. Many microcracks which formed may have gone unnoticed, because they may have closed due to the relief in stress. Again, this may account for in part the high values received by Hsu *et al.*

In Hansen's investigation, surface microcracks were observed. Hansen applied a purely axial compressive stress field to the concrete models. Under an axial load microcracks are believed to originate in the center of the concrete models and then propagate to the outer surface. Under this assumption, microcracks would not be noticed on the surface of the models until higher compressive stress fields were reached. This may account for the differences received by Hsu *et al.* and Hansen as far as bond microcracks are concerned.

Conclusions

The following are some of the conclusions drawn from this investigation:

1. Procedures, techniques, and apparatus were developed and/or modified for the study of concrete fracture utilizing the SEM.
2. Microcracks were found to exist in concrete prior to application of compressive stress fields. These initial microcracks are shrinkage microcracks. These shrinkage microcracks were in the form of bond microcracks (microcracks at the interface between the aggregate and the matrix) with matric microcrack extensions (microcracks in the paste).
3. Shrinkage microcracks (initial bond microcracks) propagate into the matrix and widen under an increasing compressive stress field. As the compressive stress field approaches the ultimate strength of concrete these

microcracks become macrocracks and with time will fail the member.

4. Under increasing compressive stress fields (as low as 15% of the ultimate strength) matrix microcracks widen and propagate to the point they begin to bridge bond microcracks.
5. At 45% of the ultimate strength of concrete the bridging of the bond microcracks is about complete.
6. At 75% of the ultimate strength of concrete the bridging of the matrix microcracks begins and as the compressive stress field is further increased it is conjectured that these microcracks will continue to widen and propagate until failure occurs.

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Prokopicrinidae, New Family of ?Camerate Crinoids, Silurian (Wenlockian-Ludlovian), Tennessee and Oklahoma

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ABSTRACT

The new Silurian platycrinitacean crinoid genus *Prokopicrinus* represents an extreme in calyx simplification among camerates. Perfectly pentamerously symmetrical aside from the tripartite base, these diminutive (width 1.4–1.8 mm) monocyclic crinoids lack interradials and anal plates or other indicators of the position of the anal opening and can be oriented only by reference to the azygous basal (located in EA interray?). The family Prokopicrinidae (nov.) probably are descended from the Hirneacrinidae, culminating a trend in the superfamily Platycrinitacea toward expulsion of the interradials (including the primanal) from the cup.

The Prokopicrinidae differ from the Hirneacrinidae and Hapalocrinidae in their small size, and lack of both a differentiated CD interray and of interradials (IRR) participating in the calyx; hence these crinoids cannot be assigned to existing families. Parallel evolutionary trends in the inadunate orders Disparida (monocyclic; microcrinoids and an undescribed hapalocrinitid) and Cladida (dicyclic; *Elicrinus* Prokop, 1973) produced similar-appearing genera; assignment of the family to the Camerata is not indubitable.

Three new species are placed in *Prokopicrinus*: *P. tuberculatus*, the type species, is a depressed bowl-shaped form with tumid plates, impressed plate sutures, and irregularly developed tuberculate surface. *P. laevis* is characterized by a deeply bowl-shaped cup and smooth plates without impressed sutures. These 2 species are from the Henryhouse Formation (Ludlovian), Oklahoma. *P. barricki* (Wenlockian; Waldron Shale, Tennessee) has a basal flange, pentalobate calyx, and unevenly pitted ornamentation (prosopon). All 3 were members of a sparse, relatively deep-water crinoid assemblage typified by an abundance of *Pisocrinus*, *Lecanocrinus* and other flexibles, calceocrinids, and microcrinoids. The small size of *Prokopicrinus* and associated taxa, plus preservational factors, suggest a soft-bottom habitat with a slow or moderate sedimentation rate and weak currents. The assemblage is possibly analogous to the *Dicoelosia-Skenidioides* Community of Benthic Assemblage 4 of Boucot (1975).

The echinoderm fauna of the classic Waldron Shale (Wenlockian) localities in Indiana has been fairly well known for almost a century (Hall, 1879); not so the echinoderms of equivalent strata in Tennessee. An analogous situation obtains for the Henryhouse Formation (Ludlovian) of Oklahoma; the crinoids of the typical facies were monographed by Strimple (1963), but those from what we interpret as a deeper water facies have been neglected. Crinoids recovered recently from some Waldron and Henryhouse shale samples are significantly different from those of well-known localities. Common to both formations are abundant pisocrinids and calceocrinids, microcrinoids, and *Lecanocrinus*. Rare are the large camerates normally quite common in both. The Henryhouse sample has abundant *Gissocrinus*; this genus has not been found in the Waldron, but small *Stephanocrinus* is exceedingly abundant.

Brachiopods and ostracods are the only other common invertebrate groups. Fewer than the usual complement of brachiopod genera are present; *Dicoelosia* is quite abundant. Almost all the crinoids and brachiopods are small;

many of the crinoids fall into the microcrinoid and minicrinoid (term defined herein) size ranges, being less than 5 mm in width. The crinoids described below exemplify this observation; though fully adult, none exceed 2 mm in diameter. This has unfortunately precluded photographic illustration of the new taxa, and camera lucida sketches are used instead. Also hampering taxonomic treatment is the rarity of complete calices (isolated radials are common) and the simple structure of many of the new crinoids. Large-scale bulk processing has not been attempted; though shaley, the samples can be only partially disaggregated by standard procedures. No crowns have yet been recovered, and isolated skeletal elements are many times more abundant than articulated calices.

The extremely simple nature of the calyx plate configuration of the crinoids herein named *Prokopicrinus* makes it impossible to assign them unequivocably even to subclass level. Nevertheless, recent work on the early history of the divergent camerate superfamilies Patelliocrinacea and Platycrinitacea allows placement of the new genus and family in the latter with some confidence. Well known phylogenetic trends within the two superfamilies (Brower, 1973; Frest and Strimple, 1977) reach their apogee in the Prokopicrinidae; the existence of such forms could easily have been predicted from previously known information. Convergent evolution produced similar forms in the Inadunata at about the same time; these crinoids are, fortunately, not perfect homeomorphs of the Prokopicrinidae and can be separated from the camerates on various grounds.

All specimens have been placed in the Repository, Department of Geology, University of Iowa.

Systematic Descriptions

Class CRINOIDEA Miller, 1821

Subclass CAMERATA Wachsmuth and Springer, 1885

Order DIPLOBATHRIDA Moore and Laudon, 1943

Superfamily PLATYCRINITACEA Austin and Austin, 1842

Diagnosis.—Calyx tending to be confined to lowermost 2 plate circlets (patina); basals (BB) 3, unequal (small one normally in AE interray) or fused; brachials and interbrachials generally little or not at all represented in calyx. Proximal brachials tending to stand out clearly from radials (RR) although joined firmly to calyx, tegmen, or both by interradially situated plates in primitive members; interradials absent in advanced members; posterior side slightly or not differentiated in calyx (adapted from Ubaghs, 1978).

Range.—U. Ordovician—Permian, worldwide.

Included families.—Platycrinitidae Austin and Austin, 1842; Hapalocrinidae Jaekel, 1895; Hirneacrinidae Frest and Strimple, 1977; Prokopicrinidae (nov.).

Remarks.—Our concept of the Platycrinitacea is essentially identical to that promulgated by Ubaghs (1978) except for a few points. We place the Marsupiocrinidae in the Patelliocrinacea, rather than the Platycrinitacea; the rationale for our preference is given in Frest and Strimple (1978). Addition of the Hirneacrinidae and Prokopicrinidae to the superfamily since Ubaghs' work was written necessitates minor emendation of his superfamilial diagnosis. The additional two families represent the culmination of certain phylogenetic trends first recognized by Brower (1973) but implicit in Ubaghs' diagnosis within the closely related Patelliocrinacea and Platycrinitacea. Most important is a tendency to reduce the calyx to a patina of BB and RR; concomitantly the IRR and anals disappear or are expelled from the calyx onto the tegmen, the arms may become completely free at the RR, and near perfect pentameral symmetry is achieved.

None of the half dozen *Prokopicrinus* specimens thus far recovered preserve the tegmen; this is analogous to the situation in the Hirneacrinidae (Frest and Strimple, 1977). Its lack of prominence can be inferred readily from the observation that the edges of the RR extend onto the oral surface, covering much of it (figs. 3, 6, 9). This arrangement is also duplicated in the Hirnecrinidae and suggests that only a small number of plates constituted the tegmen and that the structure was loosely sutured. If so, this contrasts strongly with the multi-plated, prominent, and rugged tegmen characteristic of the Platycrinitidae and militates against that family as ancestral to the Prokopicrinidae.

Family PROKOPICRINIDAE, new family

Diagnosis.—Calyx diminutive, pentagonally symmetrical, bowl-shaped, confined to patina of 5 RR and three unequal BB, small B in AE interray; posterior side not differentiated, tegmen not prominent. Column round, homeomorphic. Arms and tegminal plating unknown.

Included genus.—*Prokopicrinus*, new genus.

Range and distribution.—M.—U. Silurian (Wenlockian-Ludlovian), Tennessee and Oklahoma.

Remarks.—The Prokopicrinidae is closely related to at least 2 platycrinitacean families. It differs from the Hirneacrinidae in that the latter still has IRR notching the RR and a differentiated CD (posterior) interray. Crinoids of the Platycrinitidae are generally large, have a prominent dome-shaped tegmen, and possess elliptical and twisted synarthrially articulated columns (Lane, 1978; Broadhead and Strimple, 1977). Such features as stratigraphic range, reduced tegmen and IRR, plus the infolded tops of the RR support direct descent from the Hirneacrinidae, rather than either independent origin from the Hapalocrinidae or derivation from supposed early platycrinitids.

Though quite small, these crinoids are adults; no larger calices or isolated plates have been found despite protracted search. We do not consider *Prokopicrinus* a microcrinoid. Though the term "microcrinoid" (*sensu lato*) can embrace a fairly wide size range (Arendt, 1970) we prefer to restrict it to those crinoids having a considerable part of their potentially preservable ontogenetic development taking place at sizes below 1 mm: such crinoids, we believe, constitute a homogenous group unrelated to the presently considered forms. For those macrocrinoids that are unusually small we propose the term minicrinoid. Arbitrarily a maximum adult "size" (A ray-CD interray width at tops of RR) of 5 mm is a convenient breaking point while a minimum in excess of 1 mm (for the youngest calcified stages) can be used to delimit the lower end of the minicrinoid size range. This small size very probably has functional consequences. Many, if not all, minicrinoids may have been competing primarily with microcrinoids and may have been capable only of tentacular or limited mucus-net feeding, analogous to the pentacrinoid larval stage of modern Articulata.

The simple structure of the calyx and, especially, the lack of a differentiated anal side makes orientation difficult. Lacking morphologic criteria we fall back on phylogeny. The system adapted here (figs. 1, 12) is based on the assumption that the genus is a platycrinitacean and hence has the small basal in the AE interray—a defensible but hard to prove contention.

Genus *Prokopicrinus*, new genus
Figures 1, 12

Diagnosis, range, and distribution are the same as those given for the family.

Type species.—*Prokopicrinus tuberculatus*, n. sp., Henryhouse Formation (Ludlovian).

Derivation of name.—We take considerable pleasure in naming this genus after Rudolph J. Prokop, Narodni Museum, Czechoslovakia.

Prokopicrinus tuberculatus, new species
Figures 9–11

Diagnosis.—Calyx depressed, much wider than high; BB barely visible in side view; plates tumid, irregularly tuberculate, sutures deeply impressed; prosopon consists of numerous small tubercles, irregular in size and arrangement; no basal flange.

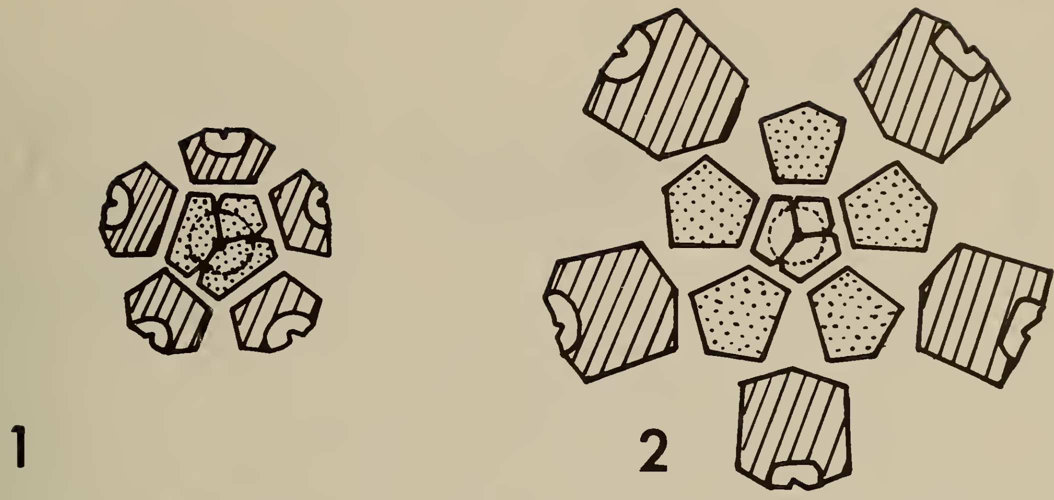


Fig. 1–2. Plate diagrams: 1, *Prokopicrinus*; 2, *Elicrinus*. Infrabasals white, basals dotted, radials obliquely lined. Presumed A ray uppermost.

Material.—A single specimen, the holotype (SUI 44341), recovered from weathered material derived from the upper part of the Henryhouse Formation, NW 1/4 NW 1/4 SW 1/4 sec. 33, T 3 N, R 6 E, Ahloso quadrangle, Pontotoc County, Oklahoma.

Description.—Calyx outline rounded to pentagonal due to slight protrusion of R arm facets and tumid plate centers; calyx small (see in Table 1), depressed bowl-shaped. BB 3; 2 equal, 5 sided in plan view (fig. 11), centered in B and D rays; smaller B (in AE interray) 4 sided in bottom view; B circlet small, about ⅓ maximum calyx diameter, pentagonal, barely visible in side view (fig. 10). Stem facet protruded slightly, circular, ½ width of B circlet; lumen small, circular. RR 5, equal, making up most of calyx height, upper edges extending onto oral surface and covering approximately ⅗ of its area. Arm facets semicircular, peneplenary, declivate, surrounded by indistinct rim; axial canal not separate. Arms and tegmen unknown. Plates thick, tumid, with moderately impressed sutures; outer plate surfaces covered irregularly with variously sized, low rounded tubercles. The tumidity of the BB gives the impression of an insignificant basal flange.

Derivation of name.—Suggested by plate ornament.

Remarks.—*P. tuberculatus* somewhat resembles *P. barricki* in calyx shape but the details of plate thickness. ornament, and other characters are distinctive. From *P. laevis* the species can be differentiated by the less prominent BB as well as the surficial differences indicated by the trivial names. The calyx shape and large arm facets are superficially similar to those of *Hirneacrinus*. The species is much larger than the remaining 2 (Table 1).

Prokopicrinus laevis, new species
Figures 6–8

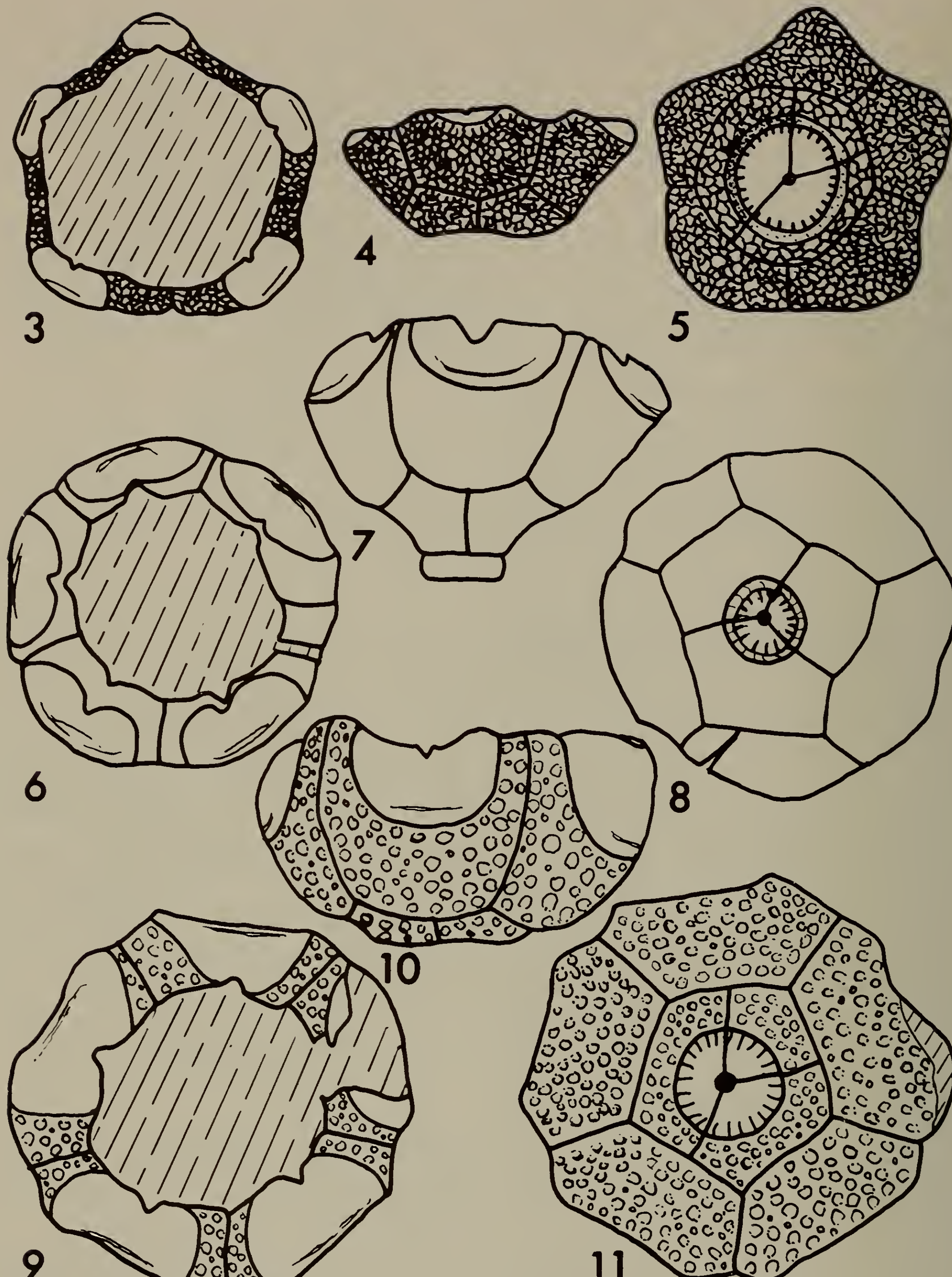
Diagnosis.—*Prokopicrinus* with only slightly wider than high, bowl-shaped calyx having prominent (in lateral view: fig. 7) BB and smooth plates without impressed sutures. No B concavity or flange.

Material.—An isolated calyx lacking the tegmen; one radial fractured. Provenance same as preceding species; holotype SUI 44340.

Description.—Calyx outline subcircular except for barely perceptible protrusion of R arm facets (figs. 6, 8); diminutive (see Table 1), only slightly

Table 1.—Measurements of _Prokopicrinus_ species (holotypes).

Name	A-CD Width	Height	Diameter of column facet	H/W ratio	Calyx width/column facet width
P. tuberculatus	1.83 mm	1.07 mm	0.50 mm	0.55	3.66
P. laevis	1.56 mm	1.10 mm	0.40 mm	0.71	1.42
P barricki	1.43 mm	0.57 mm	0.47 mm	0.40	2.51



Figs. 3–11. Camera lucida drawings of holotypes of *Prokopicrinus* species: 3–5, *P. barricki*, n.sp. (SUI 44338); 6–8, *P. laevis*, n.sp. (SUI 44340); 9–11, *P. tuberculatus*, n.sp. (SUI 44341). Each set consists of a top, side, and bottom view; all drawings ×25.

wider than high. B circlet roughly pentagonal; B shapes and orientation as in *P. tuberculatus*; circlet wide (½ calyx width as viewed from below), distally protruded from calyx into stem facet, making up about ⅓ of total calyx height (fig. 7). Stem facet circular, narrow (less than ¼ greatest calyx diameter); holotype retains a single narrow cylindrical columnal with small circular lumen and crenularium not prominent; 5 equal RR infolded onto the oral surface in a manner and degree comparable to *P. tuberculatus* (fig. 6); arm facets semielliptical, declivate, much wider than high, approaching full width of RR, notched proximally by combined axial canal and ambulacral tract; subdued rim around distal perimeter. Plates smooth, thick but not tumid, sutures not impressed. No suggestion of basal flange. Arms and tegmen unknown; latter would roof less than half of the flattened oral surface.

Derivation of name.—The specific epithet refers to the unornamented plates.

Remarks.—*P. laevis* is most comparable to *P. tuberculatus*; specific differences have been noted under the latter's description.

***Prokopicrinus barricki*, new species**
Figures 3–5

Diagnosis.—A species of *Prokopicrinus* characterized by its pentalobate calyx (figs. 4, 6), basal flange and accompanying narrow basal concavity, and pitted plate surfaces.

Material.—Three calices (holotype SUI 44338; unfigured paratypes SUI 44339), from a sample of Waldron Shale collected by James Barrick, University of Iowa. The sample was obtained from an 8 cm thick shale bed immediately above the Waldron-Laurel contact in the abandoned Franklin Limestone Company quarry north of Clifton, Wayne County, Tennessee (Clifton 7½′ quadrangle: Tennessee coordinates 378,000N, 1,412,250E).

Description.—Calyx small (less than 1.5 mm wide: see Table 1), pentalobate in plan view, wider than high; holotype more flat based and depressed than paratypes. Outline of B circlet rounded, only faintly pentagonal (fig. 5). BB prominent in side view (fig. 4), distally produced into basal flange surrounding comparatively wide (⅓ calyx diameter) column facet. The circular stem facet is impressed into BB; B concavity has narrow periphery separating stem facet from basal flange. RR 5, large, much wider than high, onlapping oral surface less than in other *Prokopicrinus* species (fig. 3), produced into broad lobes strongest near center of upper edges. Arm facets narrow, almost quadrangular in shape, not exceeding ½ greatest R width; orientation nearly horizontal. Facets on lobate portion of RR, notched by axial canal-ambulacral tract. All calyx plates with coalescing, irregularly polygonal, shallow pits; plate sutures not impressed. Proximal columnals (removed in cleaning) short cylinders with tiny circular lumen; crenularium distinct, simple, narrow. Arms and tegmen not preserved.

Derivation of name.—The species name honors the collector, James Barrick.

Remarks.—Calyx shape, atypically wide tegminal region, and narrow arm facets suggest that *P. barricki* is more distantly related to *P. laevis* and *P. tuberculatus* than the 2 latter species are to each other. Too little is known about the phylogenetic significance of specific taxobases in *Prokopicrinus* to permit evaluation of interrelationships at the species level. The peculiar surface features, reminiscent of the outside surface of hammered aluminum kitchen ware, are rare among crinoids; the unrelated disparid inadunate *Apodasmocrinus punctatus* (Brower and Veinus, 1974) is the closest parallel.

Paleoecology

Boucot (1975: 206) interprets the Henryhouse and Waldron brachiopods as quiet water communities. Supporting this assessment are the fine-grained matrix and the abundance of unusually small brachiopod taxa. The suite of genera found in the Waldron sample best fits the *Dicoelosia-Skenidioides* Community of Benthic Assemblage 4 (Boucot, *op. cit.*: fig. 4 and p. 247) and may represent a deeper environment of deposition than does the typical Waldron. All brachiopods recovered are small, *Sphaerirhynchus* is absent and *Atrypa* is rare, while *Dicoelosia*, *Nucleospira*, *Coelospira*, and *Skenidioides* are unusually abundant. *Dalejina*, *Reserella*, *Isorthis*, and *Howellela* are equally represented in both areas. Pelecypods are extremely rare, and few corals are present. Ostracods and bryozoa are most conspicuous in abundance after brachiopods and echinoderms, but sponges are also present. Conodonts are exceedingly rare. Echinoderm genera include common *Stephanocrinus*, *Lecanocrinus pusillus*, "*Deltacrinus*" *stigmatus*, and *Pisocrinus* s. l. The last has not previously been found in the Waldron; other such genera (besides *Prokopicrinus*) include *Zophocrinus*, an undescribed pygmaeocrinid, and *Thalamocrinus*. Many forms common in the typical Waldron are rare or absent here (*e.g.*, *Eucalyptocrinites*, *Macrostylocrinus*, and *Lyriocrinus*) while others which are normally uncommon become relatively abundant (calceocrinids, microcrinoids). Other echinoderms, including *Decaschisma* (Blastoidea) and cyclocystoids, are present in about equal numbers in both.

The Henryhouse *Prokopicrinus*-yielding sample is quite similar. The flexible crinoid *Lecanocrinus* and some inadunates (*Pisocrinus*, *Gissocrinus*) are common, while large camerates are relatively rare. As in the Waldron sample, microcrinoids and calceocrinids are abundant. *Zophocrinus* is among the characteristic genera, while some forms not previously reported from the Henryhouse (undescribed pisocrinid, *Hexacrinites* sp.) are also present. The brachiopod fauna of the Henryhouse constitutes the only cited example of the *Dicoelosia—Orthostrophella* Community (Benthic Assemblage 3) of Boucot (1975: 249) (=Henryhouse Community of Boucot, 1970). Those in our sample show a generic composition and relative abundances much like those in the Waldron sample, from which we have not yet recovered *Orthostrophella*.

The value of the echinoderm taxa as environmental indicators is not well

Figs. 12–14. Plate diagrams showing presumed evolution of the Prokopicrinidae: 12, *Hagnocrinus* (Hirneacrinidae); first interradials (including larger primanal) still notching radials; 13, hypothetical intermediate form with primanal only still in cup; 14, *Prokopicrinus*. Rays lettered according to Carpenter system; basals white, radials black, lateral first interradials stippled; primanal scored obliquely.

established. *Pisocrinus* s.l. occurs in a variety of habitats (Ausich, 1977) but is perhaps most characteristic of moderately deep and quiet water and soft bottoms: Ausich (1977: 684) interprets it as a low-energy rheophile. *Gissocrinus* was found by Lowenstam (1957) to be restricted to less turbulent environments in the northeastern Illinois Silurian. The genus is abundant in the Laurel, the echinoderm-bearing part of which may have been deposited in moderately deep water with relatively weak currents and a slow sedimentation rate (Frest, 1975). It is absent from the Racine reefs but flourishes in the non-reefal Brownsport (Springer, 1926). Certainly its bizarre arm morphology (Springer, 1926: 135–137) is unlikely to be competitive in turbulent environments. Similar conclusions can be drawn from the small inadunates. Breimer and Macurda (1972: 300) suggest that pisocrinids and microcrinoids formed a rheophobic understory in crinoid communities with abundant large rheophiles. Whether these crinoids are termed low-energy rheophiles or rheophobes is primarily semantic; a relatively quiet environment is suggested.

A small sized brachiopod assemblage suggests a soft-bottom, quiet water habitat (Boucot, 1975). Brower (1975) and Watkins and Hurst (1977) interpret Silurian small-sized crinoid assemblages similarly. The latter authors emphasize the soft bottom aspect as the controlling factor (Watkins and Hurst, 1977: 213–216). This is certainly not always the case, as some large camerates like the Silurian-Devonian *Eucalyptocrinites* thrived equally well on soft or hard substrates (Halleck, 1973 and personal observation), while, as acknowledged by Watkins and Hurst (1977: 216), such diverse assemblages as that at Crawfordsville (Lane, 1973) belie the presumed connection between substrate and crinoid size and diversity in the later Paleozoic. Combined with some other factors (mentioned above) the suggestion may have merit.

In the present examples other lines of evidence can be cited aside from size and substrate. Some of the brachiopods and most echinoderms are disarticulated. No crowns have been recovered and there is little indication that either brachiopods or echinoderms are in life position. This is consistent with a low or moderate rate of sedimentation; transport is here not plausibly a factor of importance. Overall, the evidence suggests a relatively quiet water, soft bottom environment, with sediment accumulation taking place at a moderate depth and at a comparatively slow rate. The similarities between the two faunas (abundant *Pisocrinus*, microcrinoids, and calceocrinids, similar generic composition, with common inadunates and flexibles and scarce camerates; small individuals) may indicate the existence of a discrete assemblage that is a parallel to the brachiopod-based Benthic Assemblage 4 of Boucot; this possibility requires further investigation, however.

Affinities

A crinoid with a plate configuration like that of *Prokopicrinus* could be either an inadunate or camerate. Our choice of the latter, as discussed above, is based in part on the morphology of the basal circlet and even more on the overall resemblance of the genus to some definite camerates (platycrinitaceans, noteably the hirneacrinids) and on the reconstruction of phylogenetic trends within the Platycrinitacea. As these have been the subject of 2 recent papers (Brower, 1973; Frest and Strimple, 1977) as well as having been outlined above, the arguments will not be recapitulated here. A tentative phylogeny of the relevant families is presented as Figure 15.

The addition of the Hirneacrinidae and Prokopicrinidae to the picture serves mainly to emphasize the distinctness of the Platycrinitacea from the Patelliocrinacea. The former, including some of the most morphologically specialized (evolutionarily advanced?) camerates, shows a conspicuous tendency toward

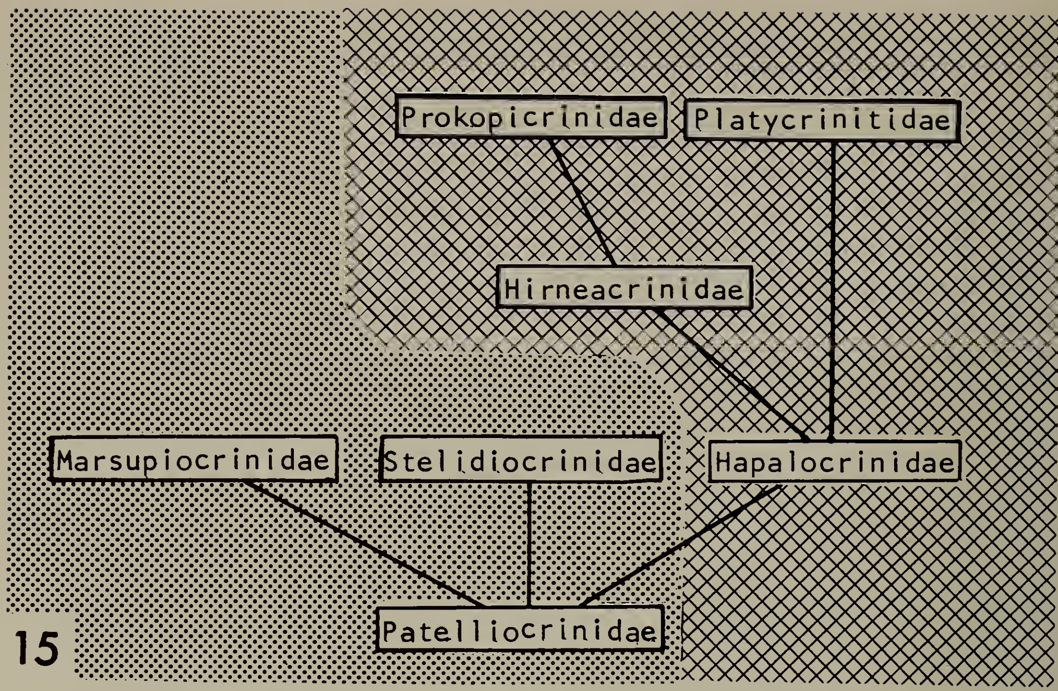


Fig. 15. Possible phylogeny of the patelliocrinacean and platycrinitacean families. Superfamily Patelliocrinacea dotted; Platycrinitacea crosshatched.

acquisition of inadunate-like cup [here better termed calyx (Ubaghs, 1978)] features. This divergence from main camerate lines (*i.e.*, crinoids with a many-plated dorsal cup including fixed brachials and numerous plates in interradial position) was evidently only partially successful. The early platycrinitacean families (Hapalocrinidae, Hirneacrinidae, and Prokopicrinidae) are, with few exceptions, not particularly diverse or numerous, but the Platycrinitidae are sometimes spectacularly abundant in upper Paleozoic rocks and include many of the last surviving camerates. The superfamily combines the advantages of the inadunate cup (smaller and mechanically more rugged than the typical camerate calyx) with the advanced arm features characteristic of the camerates from their earliest appearance. Once the transition from uniserial or cuneate pinnulate arms to totally biserial was made (in Silurian hapalocrinids) there is little further arm evolution in the superfamily, but the calyx becomes progressively more inadunate-like.

The earliest Patelliocrinacea (e.g., *Eopatelliocrinus*) resemble other contemporary camerates, but trends toward reduction in number of calyx plates and simplification to a patina were initiated very early in the superfamily's history. They are already evident, for example, in the Upper Ordovician *Macrostylocrinus pristinus* (Brower, 1973). Within the Patelliocrinacea these tendencies are accentuated in the short-lived Marsupiocrinidae and Stelidiocrinidae; both of these groups, however, retain some fixed IRR and arm brachials, and the marsupiocrinid tegmen is many-plated and without distinguishable orals. Exacerbation of the trend toward expulsion of the IRR led to the development of the Hapalocrinidae, members of which still have one IR series and proximally fixed arms. The hapalocrinid tegmen, while simple in comparison to that of patelliocrinids, is many-plated and includes both ambulacrals and interambulacrals, as well as distinct orals and the so-called axillary ambulacrals (Breimer, 1962) in some genera. Continued evolution along the same lines resulted in 2 separate lineages. The hirneacrinid lineage, which includes the Prokopicrinidae, rapidly acquired totally free arms and eventually completely eliminated interradially situated plates from the calyx. The resultant calyx is fully pentagonally symmetrical and there is no differentiation of the posterior interray. Body volume is reduced, and the tegmen dwindles in size.

In the platycrinitid line the tegmen continues to serve a major role. In many Permian and Carboniferous species it is dome-like and rigid, apparently housing part of the body mass as well as the organ systems closely clustered about the mouth. Most platycrinitids were robust animals obviously capable of full mucus-net feeding. Some genera and species ultimately considerably simplified the tegmen (*e.g.*, Broadhead & Strimple's [1977] species) but others either retained unchanged or secondarily acquired a hapalocrinid-like tegmen (Breimer, 1962). In contrast to the short-lived specialized Silurian families the Platycrinitidae probably represent the main line of evolution in the superfamily and are very likely direct lineal descendants of early Devonian hapalocrinids. Reduction in calyx size, the noted tegmen modifications, and expulsion or elimination of fixed IRR in the Marsupiocrinidae could have produced a form like *Prokopicrinus*, but no connecting links are known and the hirneacrinid antecendents of the genus can be derived more readily from the Hapalocrinidae. Even fewer steps could produce an identical form from platycrinitid predecessors but again no intermediates are presently available: additionally, the oldest undoubted platycrinitids are Devonian in age (*Oenochoacrinus*). Derivation of the prokopicrinids from the hirneacrinids would require only continued upward migration of the first IRR, already barely participating in the cup in *Hagnocrinus*. An intermediate step, as yet undiscovered, with only the CD IR (primanal) notching the calyx, is probable (see Figures 12–14).

Similar-appearing forms have been reported among the Inadunata. Some microcrinoids (e.g., *Amphipsalidocrinus*) have comparable plate arrangements, and an *Amphipsalidocrinus*-like form (undescribed) does occur in the Waldron. However, the microcrinoids, aside from their smaller size, typically have orals that are very prominent and essentially a part of the calyx. Radials are seldom as well developed, many genera are partly or wholly abrachiate, and most have an anal opening in the side of the cup; ontogenies and detailed descriptions of the relevant taxa are in Arendt's (1970) comprehensive monograph. The oldest documented true microcrinoid occurrences are Devonian, but the group is now known to range down into the Ordovician (C. R. C. Paul, personal communication, 1977) and we have Silurian forms from several horizons.

Small Devonian crinoids originally reported as juveniles of the camerate (hapalocrinid) *Cyttarocrinus eriensis* (Hall) by Koenig (1965) have a plate arrangement identical to that of *Prokopicrinus*. However, the type B (of Ausich, 1977) pisocrinid-like arm facets and fixed orals of these crinoids suggest that they are disparid inadunates related to *Haplocrinites*; this interpretation will be documented in a later paper. These specialized features are not present in the Prokopicrinidae, thus removing them from consideration as possible antecedents to the Silurian group.

An even more remarkable example of parallel evolution is afforded by the cladid *Elicrinus* (Prokop, 1973) from the Lower Devonian of Bohemia. *Elicrinus* is perfectly pentagonal, has no anal plates, and has a restricted tegmen and prokopicrinid-like radial arm facets. If the calyx is viewed from above the resemblance to *Prokopicrinus* is perfect (Prokop, 1973: plate 1, fig. 3). However, *Elicrinus* is dicyclic and cone-shaped (compare figs. 1 and 2); accepting the fundamental nature of the monocyclic-dicyclic "schism" (Warn, 1975) the two cannot be closely related. The problematical nature of any effort to accomodate such superficially simple forms in the present classificatory system is well demonstrated by *Elicrinus*: no evolutionary intermediates are known and the same crinoid could have equally well derived from half a dozen cladid families. Prokop wisely chose to leave the genus unassigned as to family (1973: 221). Our own procedure here is perhaps rash, but we believe that our case is solid enough to justify more complete treatment than was possible with the dicyclic form.

Yet another possibility is that the known *Prokopicrinus* species are young representatives of an as yet largely undiscovered lineage of true inadunates. Any number of disparid families with documented records extending into the Ordovician or Silurian could have given rise to a prokopicrinid-like form (e.g., the Homocrinidae, Synbathocrinidae, or Ramacrinidae). Again, the problem of missing intermediates prevents resolution of the family's phylogenetic relationships. Whatever the eventual disposition of the group on available evidence, differentiation as a distinct family-level taxon seems inevitable regardless of which alternative progenitor is selected.

Acknowledgements

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Myiasis in the Eastern Box Turtle Caused by *Phaenicia coeruleiviridis* (Diptera: Calliphoridae)[1]

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ABSTRACT

Larvae of *Phaenicia coeruleiviridis* (Macquart) (Diptera: Calliphoridae) were discovered causing facultative wound myiasis in the eastern box turtle, *Terrapene carolina carolina* (L.) (Testudines: Emydidae), in Maryland. Eight larvae were recovered from a puncture wound in the turtle's body wall near the head. Adult flies emerged after a pupal period of 7 days. The turtle subsequently died.

Larvae of certain flies commonly infest wounds or traumatized tissues of man and animals. Often the larvae confine their feeding or scavenging to necrotic tissues at the site of a wound or some other lesion on the skin. Occasionally these secondary larval invaders continue to burrow beneath the dead flesh into healthy tissues or organs, resulting in serious injury or even death to the host. Such an infestation generally is termed facultative myiasis.

This paper reports a case of facultative wound myiasis caused by larvae of *Phaenicia coeruleiviridis* (Macquart) (Diptera: Calliphoridae) in the eastern box turtle, *Terrapene carolina carolina* (L.) (Testudines: Emydidae). Eight mature, third-instar larvae of *P. coeruleiviridis* were obtained from a suppurating wound in a turtle collected 2 September 1976 in Millersville, Maryland.

The infected turtle was about 10 cm long and 7.5 cm wide. It appeared lethargic and weak; the front hinge of the plastron could be pried open with an index finger. The turtle had suffered a puncture wound in the body wall dorsolaterad to the head and ventrad to the carapace. The opening formed by the wound was about 6 mm in diameter and over 20 mm deep, extending well into the body cavity. The wound was festered and was oozing a malodorous brown fluid. Several dipterous larvae were observed crawling in the wound cavity and making their way to the opening where they extruded their posterior spiracles in order to obtain oxygen. The turtle was transported to the laboratory and placed in a cage for observation.

Four larvae were plucked from the opening with forceps as they surfaced for air. These specimens were killed and preserved. On 3 September, two additional larvae were removed and placed in sand at room temperature so that they would pupate. A seventh larva was found crawling across the floor of the cage on 4 September; it was collected and placed in a separate jar of sand. On 5 September, an eighth and final larva was pulled from the wound and set up in another jar of sand. While probing with forceps, small pieces of loose, flat, calcified tissue also were removed from the turtle's body cavity.

None of the four larvae in sand had pupated by 8 September so they were placed in an environmental chamber at 13°C. The larvae pupated on 10 Septem-

[1] The opinions or assertions contained herein are the private views of the author and are not to be construed as reflecting the views of the Department of the Army or the Department of Defense.

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ber. The pupae were set up in separate, stoppered vials and retained at room temperature. Adults emerged from two of the puparia on 17 September after a pupal period of 7 days; the other pupae failed to produce adults.

The flies were identified by R. J. Gagné, Systematic Entomology Laboratory, U. S. Department of Agriculture, Washington, D. C., as *P. coeruleiviridis*. This species is common in woods and fields where it has been collected upon human excrement and decaying meats (Hall, 1948). *Phaenicia coeruleiviridis* also has been reared from nests of starlings (McAtee, 1929), and females were observed ovipositing upon the fur of a thin and emaciated kitten by Davis (1928). The animal was weak and ill but supposedly was not wounded.

The present paper is the first apparent report of larvae of *P. coeruleiviridis* causing myiasis in a vertebrate and the first recorded association between calliphorids and turtles. *Cistudinomyia cistudinis* (Aldrich), a sarcophagid fly, has been bred from sores in box turtles (Aldrich, 1916; Knipling, 1937), but this species is apparently an obligate parasite, not a facultative producer of myiasis as *P. coeruleiviridis*.

The turtle's wound remained fetid and suppurative even after the last calliphorid larva had been removed. The turtle continued to be very weak and inactive. It never drank or ate while in the laboratory, and seldom moved about the cage. It died on 30 September, 28 days after capture, probably as a result of the fly infestation.

All specimens of *P. coeruleiviridis* were deposited in the U. S. National Museum.

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Parasitism of *Trirhabda virgata* LeConte (Coleoptera:Chrysomelidae) by a species of *Aplomyiopsis* Villenueve (Diptera:Tachinidae)

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ABSTRACT

Of 69 larvae of *Trirhabda virgata* reared in the laboratory, 2 yielded tachinids of the genus *Aplomyiopsis*.

As part of a project concerning the arthropod fauna of *Solidago* Linnaeus in old fields near Ithaca, New York, phytophagous insect larvae found on or near goldenrods were reared in the lab for identification, and to see whether the larvae were targets of parasitoids frequenting goldenrod inflorescences later in the season. One such culture consisted of larvae of the chrysomelid *Trirhabda virgata* LeConte, abundant on *Solidago altissima* Linnaeus, and occasionally on other *Solidago* species.

On May 30, 1977, I collected numerous larvae, mostly last instar, and placed them in a glass quart jar with fine-mesh Dacron organdy stretched tightly over the mouth. Room temperature varied between 20° and 24°C. Fresh *S. altissima* leaves were added and old leaves were removed at least every other day. By June 13, 1977, the larvae had stopped feeding and most had curled up on the bottom of the jar. Two larvae did not curl, and each appeared to have a fly puparium inside the larval skin. On June 8, 11, and 13, 1977, all 69 larvae in the culture were transferred to the surface of a dampened peat moss-vermiculite mixture, partitioned in four cylindrical glass dishes (2.7 cm high, 5.4 cm inside diameter) with glass covers. One larva appeared to be diseased, being almost entirely covered with a white, velvety, probably fungal coating.

The 2 larvae containing puparia each yielded a tachinid of the genus *Aplomyiopsis* Villenueve (they may belong to an undescribed species (C. W. Sabrosky, personal communication); both specimens are in the U. S. National Museum). One emerged on June 11, 1977, and the other on June 16, 1977. Both flies emerged from the posterior end of the old larval skin. The remaining "undiseased" larvae eclosed between June 18 and July 1, 1977. Thus, of the 69 larvae, 1.4% were "diseased", 2.9% were parasitized by *Aplomyiopsis* sp., and 95.7% survived to eclosion.

According to Clausen (1940, Entomophagous Insects, McGraw Hill, New York, p. 430) and Sabrosky and Arnaud *in* Stone *et al.* (1965, A Catalog of the Diptera of America North of Mexico, U. S. Dept. Agr., Agr. Res. Serv., Agricultural Handbook No. 276), the species of *Aplomyiopsis* attack larvae of Chrysomelidae and phytophagous Coccinellidae. This report of *Aplomyiopsis* sp. attacking the larvae of *T. virgata* is further documentation of the parasitism of chrysomelid larvae by the genus *Aplomyiopsis* and is the first record of a tachinid parasite attacking the genus *Trirhabda*.

Parasitism of 2.9% of the *T. virgata* larvae seems to be quite low for an abundant, externally-feeding herbivore. By contrast, 16–90% of Mexican bean beetle larvae, *Epilachna varivestis* Mulsant, were parasitized by *Aplomyiopsis epilachnae* (Aldrich) in Mexico and the United States (Landis and Howard, 1940, *Paradexodes epilachnae*, a tachinid parasite of the Mexican bean beetle, U. S. Dept. Agr. Tech. Bul. No. 721: 1–31.). Of course, the *T. virgata* larvae in this culture were not exposed for their entire larval lives, nor during their pupal period, which may also be vulnerable (Clausen, 1940 *ibid.*). However, now that *Aplomyiopsis* sp. has been identified as a parasite of *T. virgata*, its impact on *T. virgata* can be more precisely assessed in future work.

Acknowledgments

I want to thank C. W. Sabrosky for identifying the 2 *Aplomyiopsis*, and E. R. Hoebeke for identifying several *T. virgata* adults. E. R. Hoebeke, C. R. Sholes, and R. H. Whittaker provided many helpful comments.

NEW FELLOWS

Henry Parsons, Executive Director, Institute for Behavioral Res., Inc., Silver Spring, Md., in recognition of his contributions to human factors/engineering psychology and to behavioral psychology (operant conditioning), in particular his work in man-machine systems and their training and experimental evaluation. *Sponsors*: John O'Hare, Sherman Ross, J. E. Uhlaner.

Tom van der Zwet, Research Plant Pathologist, USDA, in recognition of his research in fire blight of apple and pear, and in particular his contributions to breeding for blight resistance in pear. *Sponsors*: R. R. Colwell, Richard H. Foote.

INFORMATION ON SOCIETIES RECENTLY AFFILIATED

Potomac Division, American Phytopathological Society

Objectives: To bring together plant pathologists to discuss research in plant pathology and other problems of general interest and to stimulate understanding with other sciences concerned with the general problem of crop improvement.

Members: Active members must be members of the American Phytopathological Society. Persons who are not members of the APS but are interested in plant pathology are eligible for Associate Membership. Retired plant pathologists are considered honorary members. There are 238 members (from D. C., Md., Va., Del., N. J., N. C., & Yonkers, N. Y.) in the Division.

Meetings: One principal meeting is held each year with formal programs of scientific interest. At the 1976 meeting held at the Univ. of Delaware on March 17–19, a total of 50 papers were presented before various groups.

Metropolitan Washington Chapter of the Society for General Systems Research

Objectives: (1) To investigate the isomorphy of concepts, laws and models from various fields, and to help in useful transfers from one field to another: (2) to encourage development of adequate theoretical models in fields which lack them: (3) to minimize the duplication of theoretical effort in different fields: and (4) to promote the unity of sciences through improving communication among specialists.

Members: The membership is composed of professional, scientific, and academic people whose interests are broader than a particular discipline and who are pursuing the systems point of view for dealing with complex problems. There are now 100 members in the Washington Chapter.

Meetings: The chapter sponsors an annual meeting at which papers are presented and research areas discussed.

The 1975 meeting held Sept. 19–20 was concerned with "Systems Science and the Future of Health." The topic of the 1976 meeting is to be "Complexity: A Challenge to the Adaptive Capacity of American Society."

Potomac Chapter, Human Factors Society

Objectives: To (1) provide a professional forum for the exchange of multi-disciplinary ideas and information about man and his environment: (2) encourage a social relationship where members can meet and communicate freely with others who have a wide variety of viewpoints and backgrounds: (3) establish a point of contact for persons and organizations in the Potomac Chapter area who are interested in or have a need for human factors research and technology.

Members: Must be members of the National Society. Individuals not qualifying for the election to the grade of member who are interested or active in the field may become associate members. Such members may not vote or become officers. The chapter consists of 181 members.

Meetings: Not less than one regular meeting is held each year. Special meetings may be called on request of 15 members. The principal 1975 meeting was a one day symposium on "Advance Technologies in Systems Operation and Control." In 1976 there was a one-day symposium on "Training: Technology to Policy."

SCIENTISTS IN THE NEWS

NATIONAL COUNCIL OF ASSOCIATIONS FOR POLICY SCIENCES

John G. Honig was elected to be president of NCAPS at a recent election. Dr. Honig is associated with the Office of the Chief of Research, Development and Acquisition, Department of the Army, and has received wide recognition in the professional community. He is a founding member and past president of the Washington Operations Research Society and a Past President of the Military Operations Research Society. He is also a co-recipient of its David A. Rist prize for the best paper given at a symposium. Dr. Honig is also past chairman of the Military Applications Section of the Operations Research Society of America, a past treasurer and member of the board of directors of the Washington Academy of Sciences. He is a member of the Governor's (Maryland) Science Advisory Council and a Fellow of the American Association for the Advancement of Science. In recognition for his many achievements he was elected to the Cosmos Club.

AMERICAN SOCIETY OF CIVIL ENGINEERS

Eugene W. Weber, Washington, D. C., consulting engineer, today received the Julian Hinds Award from the American Society of Civil Engineers. The award was presented at the Society's 125th Annual Convention which is being held here this week.

The Award was endowed in 1974 in recognition of the outstanding professional contributions of Julian Hinds, Honorary Member of ASCE. The Award is made annually to the author of that paper which is judged to be the most meritorious contribution to the field of water resources development.

Mr. Weber receives this award for "distinguished service in planning water resources for the U. S. Corps of Engineers and the International Joint Commission; in particular for leadership in reorienting planning concepts in the Corps toward socio-environmental goals, public participation, and greater consideration of alternatives."

From 1931 to 1965 he was in the career civil service of the Corps of Engineers, Department of the Army engaged in water resource development, planning and policy. His responsibilities culminated in assignments with the Corps of Engineers in Washington, D. C. as Special Assistant to the Director of Civil Works, Chief of the Civil Works Planning Division, and Deputy Director of Civil Works for Policy. For these efforts, Mr. Weber received the Rockefeller Public Service Award in 1963, and the Defense Department Distinguished Civilian Service Award in 1963, and the Defense Department Distinguished Civilian Service Award in 1963. In 1963 he also received the Army's Exceptional Civilian Service Decoration, the highest award that can be given by the Army to a civilian employee. He retired from Federal civil service in 1965.

During World War II, Mr. Weber entered into active Army service from his reserve status as a Captain, served in Washington, London, Normandy, and Paris and returned to civilian status as a reserve Colonel.

In 1948, Mr. Weber was appointed by President Truman to serve as a Commissioner on the United States Section of the International Joint Commission, United States and Canada. He continued in this position after his civil service retirement in 1965 and until President Nixon accepted his resignation in July 1973. During that period of nearly 25 years under five Presidents, he was heavily involved in the problems of the Columbia River, Passamaquoddy Tidal Power, the St. Lawrence Project, and the air and water pollution studies in the Great Lakes which are currently a major concern of the Commission.

Since 1965, Mr. Weber has served as a consultant to the Organization for Economic Cooperation and Development (OECD) and for several Federal, state and private agencies.

OBITUARY

William R. Osgood

Dr. William Ruprecht Osgood, 82 died Sunday, September 25, 1977, at Holy Cross Hospital in Silver Spring, Md., after a brief illness. William Osgood, the oldest of three children of Professor William Fogg Osgood and Theresa Ruprecht Osgood, was born in Cambridge, Mass., on April 17, 1895. He was a great, great grandson of Dr. George Osgood and Elizabeth Otis, a daughter of General Joseph Otis, brother of the patriot James Otis.

Osgood attended Cambridge High and Latin School before entering Harvard College from which he graduated in 1917. He continued his education at the Massachusetts Institute of Technology and at the University of Illinois, where he was awarded an S.M. in engineering in 1924 and a Ph.D. in 1933.

Osgood's professional career in engineering extended over fifty years and was divided between teaching and research. His first position was as an aeronautical engineer in the Research Department at McCook Field in Dayton, Ohio, during World War I. After receiving an S.B. in Mechanical Engineering from MIT in 1919, he became an assistant in mechanical engineering there and later an instructor in theoretical and applied mechanics in the College of Engineering of the University of Illinois. From 1926–29 he was assistant professor of structural engineering at Cornell University. In 1929 he joined the staff of the National Bureau of Standards as a Materials Engineer where he worked on research problems in the Engineering Mechanics Section and conducted theoretical and experimental investigations in engineering materials and structures. From 1946–50 he worked on structural research problems of interest to the Navy's Bureau of Ships at the David Taylor Model Basin. At the Model Basin he planned and supervised research programs on structural problems involving elasticity and plasticity of materials used in the design of ships.

In 1950 Dr. Osgood returned to the academic world as Professor and Chairman of the Department of Mechanics at the Illinois Institute of Technology, where he administered the department and taught courses in mechanics. From 1955 to 1960 he was Head of the Department of Mechanics at Rensselaer Polytechnic Institute in Troy, New York. Having reached the age of 65, he retired in June 1960 as Professor Emeritus of Mechanics. His teaching and writing career was not yet over, however, and for the next nine years he was a lecturer and professor of civil engineering at the Catholic University of America in Washington where he contributed to the scientific and educational development of the engineering school and helped to build it into an important center in the field of mechanics. During his career Osgood published nearly 70 technical papers and was editor for the National Research Council of *Residual Stresses in Metals and Metal Construction*.

Osgood was a Member of the Society for Experimental Stress Analysis and the Society of Sigma Xi and a Fellow of the American Society of Mechanical Engineers, the American Society of Civil Engineers, the Washington Academy of Sciences and the American Association for the Advancement of Science. He also belonged to the Philosophical Society of Washington, the Harvard Club of Washington and the Cosmos Club. In 1970 he was awarded the Technical Achievement Certificate of the Washington, D.C. Section of the American Society of Mechanical Engineers. He was active in several committees of various professional societies and served on two advisory committees of the National Research Council.

Osgood married the late Albertine Walther in 1922. They were divorced in 1939; there were no children. He is survived by a sister-in-law, Margaret Osgood, of Norton, Mass., and a nephew, Theodore Osgood, of Chevy Chase. William Osgood joined the Religious Society of Friends in 1923 and since that time maintained membership in the Swarthmore Monthly Meeting.

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