VOLUME 48 NO. 8 MAY 1979

EARTH AND MINERAL SCIENCES

THE PENNSYLVANIA STATE UNIVERSITY, COLLEGE OF EARTH AND MINERAL SCIENCES, UNIVERSITY PARK, PENNSYLVANIA

Cleanup of Great Lakes Pollution from Land Use Activities—An International Management Effort

RICHARD R. PARIZEK, *Professor of Geology*

In late 1972, work began on a comprehensive study of pollution of the Great Lakes from land use activities. More than five years later, in July 1978, the final report of the study was issued. This article outlines the method of approach to this study and reports some of its results.

The study was the work of the International Reference Group on Great Lakes Pollution from Land Use Activities (referred to from here on by its acronym, PLUARG). The reference group was appointed by the International Joint Commission (IJC), which is made up of three commissioners from Canada and three from the United States and was formed as a result of the Boundary Waters Treaty signed by the two countries in 1909.

One of the IJC's major responsibilities falls into the category of "references," investigations of specific problems—such as pollution of the Great Lakes—referred to the commission by the two governments.

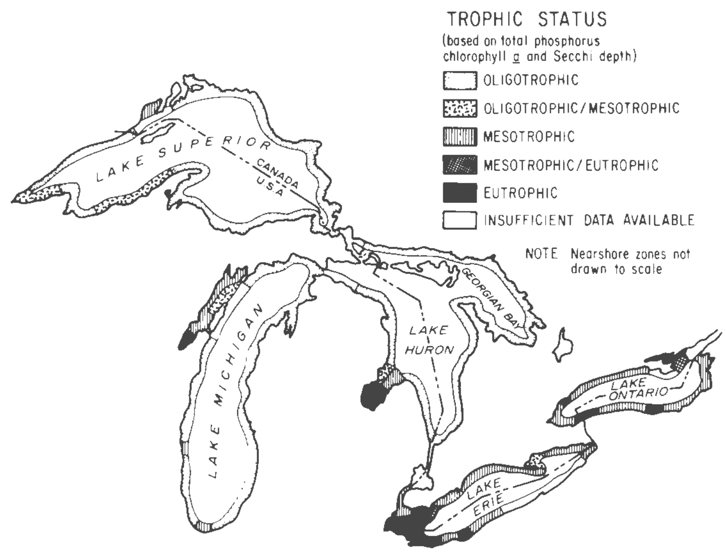

Figure 1. Nearshore trophic condition of the Great Lakes as modified from PLUARG.[4]

In 1969, studies requested by the IJC on water quality in Lakes Erie and Ontario (the lower Great Lakes) demonstrated that diffuse land drainage sources of pollutants were not only significant, but also extremely variable, and,

Continued on next page

Liquid-Liquid Extraction—Mixing Oil and Water to Extract Metals

K. OSSEO-ASARE
Assistant Professor of Metallurgy

Metallurgical application of liquid-liquid extraction, popularly known as solvent extraction or simply SX, dates back to the 1940s. At that time, the technique, which involves chemically separating the components of a liquid solution, was used to recover uranium from leach liquors and to separate fission products.

However, the growth of metallurgical solvent extraction has been the most impressive in the last decade.[1,2,3] This growth has been closely associated with the increasing rise of hydrometallurgy—the treatment of ores by wet chemical processes—as an alternative to traditional smelting operations.

The high cost of controlling pollution from sulfur dioxide is causing sulfide ore processors to consider hydro-

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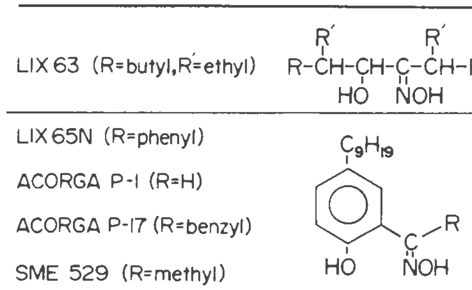

Figure 1. Some commercial oxime extractants. (The term oxime refers to the =NOH group.)

A special supplement on the College of Earth and Mineral Sciences is bound in this issue.

Earthquake Risk in Eastern Pennsylvania

B. F. HOWELL, JR.
Professor of Geophysics

Many persons have expressed surprise at the occurrence of two earthquakes in Lancaster County, Pennsylvania, last year. Actually, there is a long history of earthquakes which have occurred in eastern Pennsylvania (see table on page 63), and many that have occurred in New Jersey, Delaware, and as far away as South Carolina and Missouri have been felt in Pennsylvania. Pennsylvania is fortunate in that none of these earthquakes has been so strong that serious and extensive damage resulted.

The question occurs, however, whether with occasional small earthquakes there can some day be a large earthquake. What can we expect? No definite answer is possible until we un-

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Great Lakes Cleanup—

Continued from first page

therefore, difficult to measure. Subsequent improvements in municipal waste-water treatment facilities for point sources of pollution that had been mandated by the Great Lakes Water Quality Agreement (signed by the U.S. and Canada in 1972) magnified the relative importance of the land drainage sources of many pollutants. This made a clearer definition of the impact of land use activities and practices on water quality in the lakes necessary. The two governments requested the IJC to investigate pollution of the Great Lakes system from agriculture, urban growth, and other land use activities[1] and recommend remedial programs. Thus, PLUARG, consisting of nine representatives from each country, was formed.

More than 350 engineers, scientists, and technicians worked on the specific tasks and programs formulated by the reference group,[2, 3] and approximately $18,000,000 was committed to the study by the two countries.

(The author of this article was appointed Pennsylvania's representative to PLUARG in late 1972 and served as the U.S. chairman of Task A which was responsible for problem assessment, management, and control; definition of research needs; review and assessment of legislative, institutional, and technical remedial measures and costs; and development of public consultation panels and reviews. He presented testimony before the IJC annual meetings in 1977 and 1978 and at legal hearings on the PLUARG final report in 1978, having served as U.S. chairman of the pre-hearing public information program from July to December 1978.)

The PLUARG study had a threefold purpose: (1) to determine the causes, extent, and locality of pollution from land use activities; (2) to gain an understanding of the relative importance of the various land uses in terms of their diffuse pollutant loads to the lakes; and (3) to determine and estimate the cost of the most practical remedial measures for decreasing these loads to acceptable levels.

The study mainly considered diffuse, or nonpoint, sources of pollutants, including surface runoff from all land uses and groundwater inflows from the entire Great Lakes Basin. The atmospheric loads were also evaluated to determine their magnitude.

The terms "diffuse" and "nonpoint" are used interchangeably in the study. Pollutants from diffuse sources are those materials conveyed to the Great Lakes by natural runoff to tributaries, ditches, groundwater, or storm sewers, or as combined sewer overflows. Point sources, by contrast, are "pipeline" in nature, such as municipal sewage treatment plants and industrial wastewater discharges whether they are discharged directly to the Great Lakes or to tributaries draining into the lakes. Point and nonpoint pollutant loads were both considered when remedial program recommendations were worked out.

During the study, supporting technical papers and reports of public consultation panels were developed. Pilot watersheds were studied; tributary and shoreline loadings were estimated; assessments were made of problems, management programs, and research needs; and the legislative and institutional frameworks of the Great Lakes basin jurisdictions were reviewed.

The Area Studied

All five Great Lakes, their connecting channels, and the entire Great Lakes drainage basin, as well as drainage to the international section of the St. Lawrence River were considered in the PLUARG study (Figure 1).

The first step was preparation of an inventory of major and specialized land uses and practices in the basin. This provided an information base never before adequately assembled,[4, 7] and included information on geology, soils, mineral resources, climate, hydrology, vegetation, wildlife, waste disposal operations, high-density nonsewered residential areas, recreation lands, economic and demographic characteristics, and the use of pesticides, commercial fertilizers, agricultural manures, and highway salts. Trends in land use patterns and practices were also assessed, and projections of economic and demographic factors to 1980 and 2020 were made.[5, 7]

Sixty-one percent of the Great Lakes basin consists of woodland. Agricultural land, including cropland and pasture, makes up 24 percent of its area; urban land, including residential, commercial, and industrial areas, makes up about three percent; and the remaining 12 percent consists of recreational lands, wetlands, transportation corridors, waste disposal sites, extractive industry sites, and idle lands.

The major jurisdictions involved in the basin are the federal governments of Canada and the U.S., the province of Ontario, and the states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. As of 1975, there were approximately 6,900,000 people living in the Canadian portion of the basin, and 29,600,000 in the U.S. portion.[6, 7] A significant part of the gross national product of both nations is generated in this area which constitutes the world's largest single source of fresh water.

Types and Pathways of Pollutants

Nonpoint- and point-source pollutants identified as part of PLUARG activities are shown in Table 2. These include phosphorus, sediments, some industrial organic compounds, previously used pesticides, and, potentially, some heavy metals.[4] Only nonpoint-source pollutants are derived from land drainage.

Unit area loads were used to estimate the total tributary loadings of the pollutants to the lakes. These were calculated by dividing total estimated and measured pollutant contributions from a given land area by the size of the land area.

Two years of monitoring data were obtained from U.S. and Canadian pilot watersheds to determine a large

TABLE 1. CONCENTRATIONS OF LEAD IN GREAT LAKES FISH

Lake	No. of Fish Analyzed	Concentration (mg/kg)[a]
Superior	70	0.012-0.066
Michigan	23	Not Detected-0.54
Huron	50	0.04-0.10
St. Clair	34	0.47-0.63 [b]
Erie	49	0.04-0.12 [b]
Ontario	219	less than 1.0

[a]the accepted guideline concentration is 10 mg/kg
[b]range of mean values
Data from several sources cited in PLUARG[4]

48th Year of Publication

EARTH AND MINERAL SCIENCES

(ISSN 0026-4539)

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Published monthly from October to June inclusive by Earth and Mineral Sciences Continuing Education, 110 Mineral Sciences Building, University Park, Pennsylvania 16802. Second-class postage paid at State College, Pennsylvania 16801. Subscriptions available without cost upon request. POSTMASTER: Send address changes to *Earth and Mineral Sciences*, 110 Mineral Sciences Building, University Park, Pennsylvania 16802. U.Ed. 9-766

number of pollutant unit area loads for areas which each had a single dominant land use. Unit area loads for suspended sediment, phosphorus, and nitrogen from intensive agricultural and urban land uses were approximately all of the same order of magnitude—10 to 100 times greater than the loads for forested and/or idle land which were at or near background levels.

Unit area loads of pollutants for improved pasture, it was found, overlapped the upper range of forested and/or idle land categories and the lower range of the cropland land use category. Unit area loads of lead from general urban lands were about 10 times greater than those from the upper range of general agricultural lands and croplands. Phosphorus unit area loads for wastewater spray irrigation approximated the loads from the general agriculture, cropland, and urban categories, while nitrogen unit area loads for spray irrigation sites were up to 10 times greater than those from other land uses.[4]

It was found, too, that the most important factors influencing the magnitude of pollution from land use activities are: (1) the physical, chemical, and hydrological characteristics of the land; (2) land use intensity; and (3) the intensity of use and types of materials used within tributary watersheds.[4]

Meteorological conditions also affect annual and seasonal variations in pollutant contributions. For example, a once-in-a-hundred-year-frequency storm in the Maumee basin of the southwestern portion of Lake Erie in 1975 caused as much as a hundredfold greater sediment yield for 1975 than for 1976.

Structural remedial measures, such as sediment basins and terraces, must be designed with an assumed flood frequency in mind. However, the problem of retaining sediment and entrained pollutants on the land is complicated by the fact that fine-grained sediments act as scavengers for pollutants. These are hard to control through existing sediment control measures. Soil and water conservation measures developed over nearly a 35-year period by the U.S. Department of Agriculture were designed largely to maintain soil fertility, not for pollution control. Much remains to be learned about new measures that will be required to reduce land-derived pollutants entrained with colloidal-sized soil particles.[4]

Pathways for Pollution Migration

Diffuse-source pollutants within the Great Lakes system use all pathways by which pollutants may migrate within an environment. These include the atmosphere where they move in liquid, solid, or gaseous forms; surface water systems where they move in liquid or solid forms, and soilwater and groundwater flow systems where they are largely in dissolved form. Pollutants may be transported within lakes and be dispersed by processes of shoreline, beach, and lake bottom erosion. Lakewide currents account for the rather rapid migration of pollutants within lake water and bottom sediments and their transport along connecting channels from upper to lower lakes in the system. The importance of connecting channels in the transfer of phosphorus, for example, is shown in Figure 2.

Biological pathways are also important in the dispersion from uplands to the lake system and within the lakes. Animals, plants, fish, and insects can selectively accumulate or biomagnify contaminants which they carry in life and after death (Table 1).

It is still not clear where all of the pollutants associated with land uses originate in the Great Lakes watershed. However, because they are derived in large quantities from both metropolitan and rural areas, they cannot be controlled by a single land management program. Their control is further complicated by the fact that a significant portion of airborne pollutants originate from farming regions and metropolitan and industrial complexes that are outside the watershed, such as St. Louis, Missouri; Pittsburgh, Pennsylvania; and Albany, New York.

Also still poorly understood are attenuation mechanisms that may alter pollutants and contaminants during their transit and interim storage between their sources and ultimate sinks. Wastes applied to the land may be acted upon by physical, geochemical, and biochemical processes operating within surface water, soilwater, and groundwater flow systems that can partly or completely cleanse them from the system. Some organic substances become biodegraded during storage and transport, but may be trapped with sediment in upland lakes, marshes, and related wetlands, or be placed into temporary storage with colluvium or soil moving along slopes, or in sediment deposited along flood plains, in deltas, bays, and estuaries, or within lake bottoms.

PLUARG documented the magnitude of the total phosphorus load to the Great Lakes in 1976 and compared the loads from various sources with their recommended target loads that must be achieved to maintain or restore the lakes to a healthy trophic state (Figure 2).[4] The term trophic state is commonly used to describe the degree of fertility in a water body.

The amount of phosphorus from diffuse sources, such as tributaries and the atmosphere, was found in 1976 to make up a significant portion of the total load which varied greatly among the lake basins, as Figure 2 and Table 2 show.

No single phosphorus cleanup program could be applied to all areas of the watershed. The prolonged contribution of phosphorus to the lake system from all sources—natural and man-induced—has altered the trophic status of the near-shore waters.

The trophic state was defined by a composite of several parameters indicative of the algal productivity of water bodies.[8] These parameters included

TABLE 2. GREAT LAKES WATER QUALITY POLLUTANTS IDENTIFIED BY PLUARG[4]

I. **Parameters for which a Great Lakes water quality problem has been identified**

POLLUTANT	PROBLEM		SOURCES				REMARKS
			DIFFUSE				
	Lakewide	Nearshore or Localized	Land Runoff	Atmosphere	In-Lake Sediments	POINT	
Phosphorus[1]	Yes	Yes	Yes	Yes	Yes[a]	Yes	[a] percentage unknown, not considered significant over annual cycle
Sediment[b,1]	No	Yes	Yes[c]	Negligible	Under some Conditions	Negligible	[b] may contribute to problems other than water quality (e.g., harbor dredging) [c] including streambank erosion
Bacteria of Public Health Concern	No	Yes	Minor[d]	No	No	Yes	[d] land runoff is a potential, but minor source; combined sewer overflows generally more significant
PCBs[1]	Yes	Yes	Yes	Yes	Yes	Yes	
Pesticides[1] (Past)	Yes[e]	Yes[e]	Yes	Yes	Yes	No	[e] some residual problems exist from past practices
Industrial Organics[1]	Yes	Yes	Yes	Yes	Yes	Yes	
Mercury[1]	Yes	Yes	Minor	Yes	Yes	Yes	
Lead[1]	Potential[f]	Potential[f]	Yes	Yes	Yes	Yes	[f] possible methylation to toxic form

II. **Parameters for which no Great Lakes water quality problem has been identified, but which may be a problem in inland surface waters or groundwaters**

POLLUTANT	Lakewide	Nearshore or Localized	Land Runoff	Atmosphere	In-Lake Sediments	POINT	REMARKS
Nitrogen	No	No[g]	Yes	Yes	Minor	Yes	[g] some inland groundwater problems
Chloride	No	No[h]	Yes	Negligible	No	Yes	[h] some local problems exist in nearshore areas due to point sources
Pesticides[i] (Present)	No	No	Yes	No	No	Yes	[i] new pesticides have been found in the environment; continued monitoring is required
Other Heavy Metals	Potential[f]	Potential[f]	Yes	Yes	Yes	Yes	
Asbestos[j]	No	Yes	No	?	Yes	Yes	[j] see Upper Lakes Reference Group Report[37]
Viruses[k]	← No Data Available →					Yes	[k] better detection methods needed
Acid Precipitation	No	No[m]	No	Yes	No	No	[m] a potential problem for smaller, soft water, inland lakes

[1] Sediment *per se* causes local problems, phosphorus and other sediment-associated contaminants have lakewide dispersion

total phosphorus concentration, chlorophyll concentration, and Secchi depth (a measure of water quality).

Lakes naturally undergo eutrophication or a natural aging process which is a shift from low aquatic plant productivity to a high productivity. The poorest water quality (eutrophic to mesotrophic/eutrophic) results from heavy loadings of nutrients to the lakes, especially phosphorus. Bottom waters tend to be depleted in oxygen, growth of Cladophora—algae—tends to be excessive, tastes and odors are a problem in drinking water, the water has lost much of its transparency, and the total clorophyll levels are high.

The poorest water quality appears in Lakes Ontario and Erie, especially opposite major metropolitan areas and intensively farmed tributary watersheds containing fine-grained soils and draining into bays. Mesotrophic—intermediate between eutrophic and oligotrophic—conditions characterize nearly all the remainder of the lakes' shoreline waters.

Because of the local sediment problems, Lakes Superior, Huron, and Michigan are generally oligotrophic—of the best quality—except in Green, Saginaw, and southern Georgian Bays, Lake St. Clair, the Bay of Quinte, and the south shore, red clay area of Lake Superior.[4] Trace elements of lead, mercury, and arsenic, for example, may be attached to sediment particles and be transported from upland areas to ultimate points of deposition and long-term (geological) storage within the lake bottoms. Their concentration in lake water may be in trace or nondetectable amounts because of their low solubility. However, it appears that some elements can be remobilized by methylation processes. It has been found that microorganisms in lake sediments can convert inorganic mercury into a potent human nerve poison, methyl mercury.[4] This appears to be a common process in aquatic environments, and recent studies indicate there is a possibility that lead, selenium, and arsenic may also undergo methylation and, hence, have the potential of being released from their storage sites. For this reason, lead contained in lake bottom sediments is regarded as an inplace contaminant that may become remobilized under changing environmental conditions.

Remedial Programs

The control of diffuse pollutants entering the Great Lakes will be possible only after the portions of the watershed that contribute to water quality problems have been delineated. Despite the fact that the lakes are an interconnected system, each basin is unique in terms of its land and lake characteristics, the

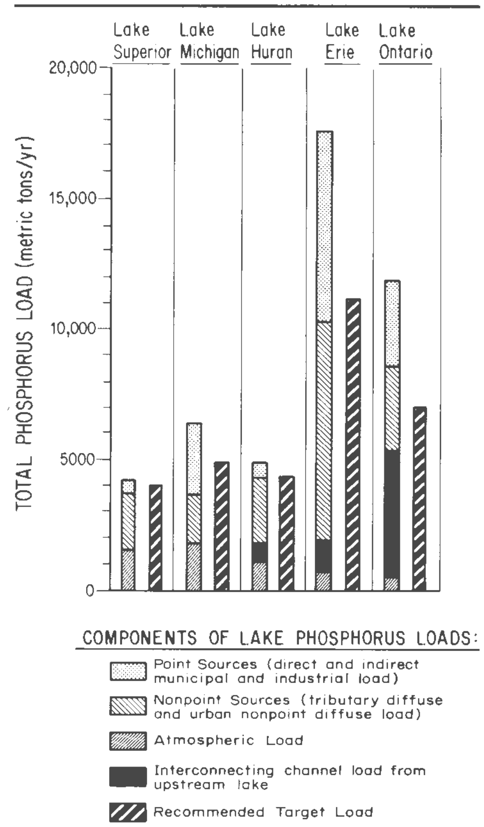


Figure 2. Phosphorus loads for the Great Lakes in 1976, their sources and recommended target loads, as defined by PLUARG.[4]

socio-economic characteristics of its communities, the type and degree of its pollution, and the physical nature of individual upland tributary basins.

PLUARG developed criteria for the identification of potential pollutant-contributing areas and, within these, the most hydrologically active areas—the zones most likely to produce water pollution from land use activities.

A hydrologically active area is one within a watershed that produces significant amounts of runoff, even during relatively minor rainfall and snowmelt events. Its soils may be poorly drained and its slopes steep, and the water table is usually at or near land surface. Areas with predominantly flat slopes, such as till plains and emergent glacial lake plains, typically are poorly drained and contain fine-textured soils. When these areas are located near water courses, surface runoff waters and entrained pollutants are delivered very efficiently to streams and lakes just as they are from more steeply sloping areas.

PLUARG pilot watershed data showed, for example, that 15 to 20 percent of the land surface may contribute up to 90 percent of the total sediment load from a watershed. Connected impervious surfaces help identify hydrologically active areas in urban areas that, in a general way, correlate with population density and land use intensity.[4]

To minimize the costs of implementing blanket remedial measures throughout the watershed, it was recommended that technical measures be applied to the most hydrologically active areas. Implementation of remedial measures on areas adjacent to these would be justified to protect the quality of upland surface water and groundwater, but not that of the Great Lakes.

PLUARG stressed the importance of recognizing: (1) the long-term nature of solutions to most problems of pollution from land use activities; (2) the ramifications of these solutions through most sectors of society; (3) the involvement of many agencies in the implementation of the solutions; and (4) the public consequences of the solutions in such policy areas as food production, housing, and public health.[4]

It was recognized that, as populations grow and industrial and economic activity continues, given current technology, pollutant inputs from both point and nonpoint sources will undoubtedly continue to grow, and the lakes have a finite capacity to accept these inputs.[4] Therefore, PLUARG recommended that appropriate pollutant loading targets be established and long-term monitoring programs be undertaken to quantify these loads to insure that the dilutant and attenuation capacity of the lakes is not exceeded. Choices for a combination of both point- and nonpoint-source control programs are available, and are part of the environmental management strategy for the Great Lakes system proposed by PLUARG.

PLUARG does not favor across-the-board measures for nonpoint-source pollution control as was required for point-source control. Rather, a comprehensive strategy for management of the Great Lakes ecosystem and a methodology to identify priority areas to be treated was developed. This strategy recognized the importance of developing management plans that include: (1) a timetable indicating program priorities for the implementation of the PLUARG recommendations; (2) identification of agencies responsible for implementation of progams designed to satisfy the recommendations; (3) formal arrangements to insure inter- and intra-governmental cooperation; (4) programs through which the recommendations will be implemented by federal, state, and provincial levels of government; (5) sources of funding; (6) estimated reduction in loadings to be achieved; (7) estimated costs of these reductions; and (8) provisions for long-term surveillance and public review.

The PLUARG final report stressed the need to attack problems on a regional priority basis, and to control phosphorus, sediment, toxic sub-

Providing Instruction and Research in the Vital Areas of Energy, Materials, and the Environment

THE COLLEGE OF EARTH AND MINERAL SCIENCES

of The Pennsylvania State University

The Edward Steidle Building

Penn State's College of Earth and Mineral Sciences is unique. Nowhere else in the world is there such an aggregation of expertise in the earth, mineral, meteorological, and materials sciences within one administrative unit of a large university.

Provision of adequate energy sources and wise use of diminishing mineral resources of all kinds have been primary concerns of this college's faculty for many years.

When continuing degradation of the environment became a national concern in the 1960s, researchers in the college had long been working to solve such ecological problems as acid-mine drainage and ever increasing air pollution. And throughout long years of meager financial support, extensive coal, petroleum, and other energy-related research and instruction continued here when these areas of study were being abandoned by many institutions. The result was that when the nation's energy problems reached critical proportions in the early 1970s, this college was ready with the personnel, facilities, and expertise needed to expand quickly its teaching and research in energy-related areas.

The Development of the College

Earth and mineral sciences education has been an integral part of Penn State's instructional program since the University first opened its doors in 1859. Three of the twelve theses prepared by the members of the first graduating class were concerned with the mineral industries. However, it was not until 1890 that a Department of Mineral Engineering was established. Successively, this became the School of Mines, was demoted to the status of a department in the School of Engineering, and then became the School of Mines and Metallurgy, as the University experienced various financial ups and downs.

Then in 1928 Edward Steidle, a man of great energy and vision who had a keen appreciation of the place of minerals in the modem world, became dean and ultimately succeeded—where others had failed—in building a firm foundation for the mineral sciences at Penn State. Under his dynamic leadership, many new programs and facilities were inaugurated, while, all the time, he worked persistently to gain adequate financial support for his school which he renamed the School of Mineral Industries.

Dean Steidle emphasized the development of strong programs in resident instruction, research, and extension (now continuing education) that embraced all of the mineral sciences. He included in those sciences such then uncommon university disciplines as geochemistry, geography, meteorology, and mineral economics. Under his guidance, the college's first two buildings—Mineral Industries (renamed the Edward Steidle Building in 1978) and Mineral Sciences—were constructed.

By his retirement in 1953, Dean Steidle had seen the undergraduate enrollment grow from 144 to 590, the graduate enrollment from none to 170, and the faculty from 15 to 60. He was succeeded by Dr. E. F. Osborn, professor of geochemistry, who served until becoming the University's vice president for research in 1959. Drs. O. Frank Tuttle, David R. Mitchell, and Richard H. Jahns then successively served short terms as dean. In 1965 Dr. Charles L. Hosler, head of the Department of Meteorology, assumed the deanship and continues to serve.

During Dean Hosler's administration, the college has been renamed the College of Earth and Mineral Sciences; two additional buildings—the Deike Building and the Eric A. Walker Building—have been completed; and the college's administrative organization has been streamlined with the merger of eleven departments into six.

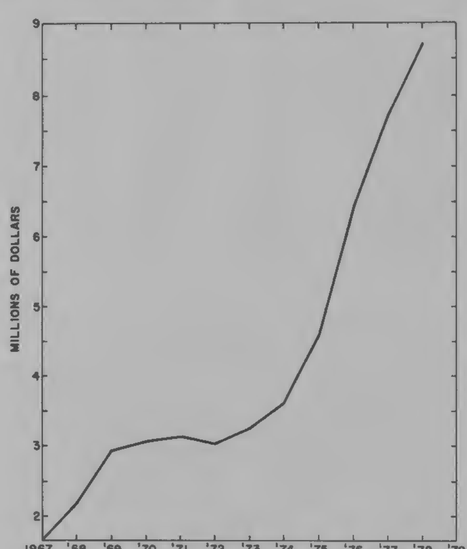
The College Today

In the past fifteen years, the college has experienced phenomenal growth, with an increase in total enrollment of 196 percent. While the total Penn State undergraduate body grew by 70 percent, the college's undergraduate enrollment increased by 275 percent to some 1,600. Meanwhile, the graduate enrollment went up by 52 percent to 500, and the two-year associate degree programs were established and now have about 140 students. Statistics also indicate that the student body reflects quality as well as quantity. More than two-thirds of the undergraduates were in the first fifth of their high school classes.

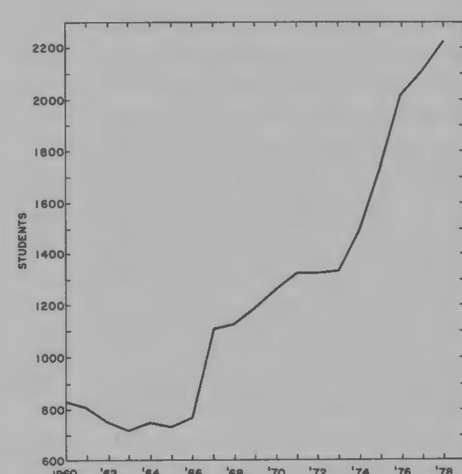
The number of degrees granted in the college has more than doubled over the past fifteen years, rising to a total of 522 in 1977-78. Of this number, 314 were B.S. degrees, 140 were advanced degrees, and 68 were associate degrees.

While the total University faculty increased by 55 percent over the past decade and a half, this college's teaching staff increased by 52 percent to a total of about 135, of whom 97 percent have doctorates. The contracts and grants for research acquired and supervised by the faculty have grown in value from about a million dollars to almost $9 million over the past decade.

In all of the disciplines offered in the college—from geography through geosciences, materials science and engineering, meteorology, mineral economics, and mineral engineering—a great many of the faculty have achieved world renown for their work. Among them are the presidents or past presidents of most of the leading professional societies in their fields. Many faculty members have received prestigious national and international awards, and a large number are serving on federal and state advisory committees and boards.



Research Funds
College of Earth and Mineral Sciences
1967-78



Enrollment
College of Earth and Mineral Sciences
1960-78

Undergraduate Programs

The College of Earth and Mineral Sciences offers ten programs leading to the B.S. degree and two leading to the associate degree. The undergraduate majors are as follow.

Ceramic Science and Engineering deals with the application of high-temperature science and engineering principles to the production of non-metallic, nonorganic materials vital for everyday life and such specialized fields as electroceramics, nuclear energy, and aerospace.

Earth Sciences provides a comprehensive program in the physical environmental sciences based on a strong emphasis in the geological sciences, meteorology, and geography. It is directed especially toward study of problems arising from man's complex interaction with the natural environment.

Geography, both a physical and a social science, describes and explains spatial patterns of environmental and human features on the earth's surface. Using the world as a laboratory, it examines natural and social phenomena in their complex interactions.

Geosciences deals with the materials that make up the earth, its internal structure, the processes that shape its interior and surface features, and the discovery, recovery, and conservation of its resources. Three options are offered—General, Geophysics, and Biogeology.

Metallurgy covers the areas of recovery, production, and refinement of metals. Metallurgical engineers design and operate metal-processing equipment, supervise production of precision alloy parts, and work to develop stronger, more corrosion-resistant metals.

Meteorology deals with the atmosphere, combining basic knowledge of physics, chemistry, and mathematics with modem tools such as radar, computers, and satellites to predict and modify atmospheric behavior and air pollution.

Mineral Economics combines the study of economics, business administration, and earth and mineral sciences to prepare the student for managerial or staff positions in the mineral industries, in mineral resource economics, and in government or private research agencies.

Mining Engineering applies modern engineering principles to the construction and operation of mines, and to the processing of coal and other mineral ores for their various uses once they are removed from the earth. Two options are offered—Mining and Mineral Processing.

Petroleum and Natural Gas Engineering deals with the exploration for, and production of, oil and gas. It involves reservoir engineering and advanced recovery techniques—processes designed to increase production from oil and natural gas reservoirs.

Polymer Science is a multidisciplinary subject encompassing elements of all the traditional sciences and specializing in the science and technology of polymeric materials—key ingredients of plastics, paints, elastomers, and adhesives.

The two associate degree programs in the college are as follow:

Mining Technology provides specially qualified people to fill the gap between the mining engineer and the miner. A Production option is offered at Penn State's Fayette (Uniontown, Pa.), Altoona, and New Kensington campuses, and a Maintenance option is offered only at Fayette.

Steel Technology prepares its graduates to fill positions that fall between metallurgical engineers and metal production workers. It is offered only at Penn State's Shenango Valley Campus at Sharon, Pa.

To assist students in its B.S. program, the college has the largest scholarship program of any of Penn State's colleges. More than $131,000 in scholarships were awarded in 1978-79, made possible by endowment funds and annual grants from various companies. Another source of financial aid for students in the college lies in work-study (cooperative education) programs in which participants alternate periods of study with time spent working for cooperating companies, gaining valuable experience while earning money.

A graduate student uses the electron microprobe analyzer.

Graduate Study

Twelve graduate programs leading to the M.S. or Ph.D. are offered in the college—ceramic science and engineering, fuel science, geochemistry and mineralogy, geography, geology, geophysics, metallurgy, meteorology, mineral economics, mineral processing, mining engineering, and petroleum and natural gas engineering.

In addition, the college participates in four intercollege graduate programs—earth sciences, environmental pollution control engineering, mineral engineering management, and solid state science.

Research in the College

In 1977-78 the college received more than 300 grants in support of research from industry and the state and federal governments. Objectives of this research are twofold—to expand the frontiers of knowledge, and to ensure optimum educational opportunities for the students.

In addition to a variety of research efforts in each of the disciplines, there are in the college several specialized interdisciplinary research groups—the coal research, ore deposits research, and mineral conservation sections, and the Mining and Mineral Resources Research Institute. The college faculty are also very active in the University's intercollege research programs such as the Materials Research Laboratory and the Institute for Research on Land and Water Resources.

The college has facilities and instrumentation for classical chemical analysis of metals and silicate and carbonate rocks; X-ray crystallography; electron microscopy and diffraction; and electron microprobe, atomic absorption, and spectrochemical analysis.

The Earth and Mineral Sciences Library, a branch of the University's Pattee Library, conveniently located in Deike Building, shelves 58,000 volumes pertaining to the college's disciplines and receives 1,200 periodicals and serials and fifteen major indexing and abstracting tools.

Brief descriptions of a few of the many areas of research in the college follow.

Geochemists are working on a major problem in the use of geothermal waters to produce energy—the clogging with mineral scale in a relatively short time of the pipes through which the hot mineral-rich waters circulate. Because the waters have compositions much like those believed to have been responsible for hydrothermal ore deposits, this work has a dual goal—to solve the scaling problem and to gain a better understanding of hydrothermal processes as a basis for mineral exploration.

Using sophisticated instrumentation in the college's new weather observatory—perhaps the most advanced such facility at any U.S. university—meteorology faculty are developing computer techniques for handling weather data that are making speedier and more accurate forecasting possible. The new techniques, which make use of satellite pictures and radar-detected precipitation patterns as well as the computer, are being used for both research and instruction.

Mineral processing engineers are studying the fine pulverization of coal in various types of grinding machines. The data they are gathering are being used to establish design and operation procedures for coal grinding that will enable industry to perform this high-energy-requiring operation in the most efficient manner possible.

Coal researchers are developing the Penn State/Department of Energy Coal Sample Bank and Data Base which will ultimately contain data on sample source, geology, composition, and technological behavior for as many as 1,300 U.S. coal seams. This computerized research tool serves as a valuable reference for Penn State and other researchers doing studies that relate the composition of a coal to its behavior during beneficiation, liquefaction, gasification, and combustion.

Because material substitution plays a major role in the growth of material demand, mineral economists are investigating under what conditions certain materials are substituted for others in the making of such products as beer and soft drink containers.

Research on tertiary oil recovery methods by petroleum engineers is aimed at producing more oil from old oil fields. The researchers are working with the micellar-polymer process in which a detergent (micellar) material is pumped into an injection well and "sweeps" through the oil-bearing rock. Then a polymer solution (a gel or thickened water) is injected behind the detergent to push it and the oil through the rock until the oil eventually reaches a producing well area from which it can be pumped to the surface.

Ceramic engineers are studying fracture mechanics of ceramic materials, trying to learn more about how cracks develop in these materials and how they react to machining and under impact, with the goal of finding ways of producing more durable ceramics for a variety of modern products including the turbine engine.

Geographers, interested in knowing more about the trend that finds nonmetropolitan area manufacturing employment increasing while the number of such metropolitan jobs is decreasing, are looking at the kinds of plants being built in nonmetropolitan areas, what they manufacture, what led to the decisions to locate them there, and their effects on their localities.

Using electrochemical techniques, metallurgists are investigating the costly and baffling problem of the hydrogen embrittlement or cracking of steels and various alloys which results from the diffusion of hydrogen into the metal.

The removal of methane gas from coal seams prior to mining is being studied by mining engineers for the dual purpose of making mining safer and possibly realizing an economic benefit from the gas recovered.

Rock mechanics specialists are recording and analyzing acoustic signals—termed microseismic activity or acoustic emission—from underground gas storage reservoirs in a project aimed at determining the optimum pressurization for such reservoirs.

Continuing Education and Service to the Public

The college sponsors an extensive program of short courses, conferences, and workshops designed to acquaint the participants—who come largely from industry and government—with new developments in a variety of fields in which the faculty have expertise. About 1,000 people a year attend these programs which include such topics as lime manufacture, water pollution control in coal mining, application of fracture mechanics to ceramics and glass, coal characteristics and conversion, and mine cost analysis and control.

Two special programs of service to Pennsylvania's coal mining industry are conducted by the Department of Mineral Engineering. These are the thirteen-year-old Mine Mechanics and Electricians School at Elders Ridge, Pa., which now has about 100 graduates a year; and the new-miner orientation program which trains people just beginning work in mines and also provides refresher training for working miners, serving about 2,000 workers a year.

The Eric A. Walker Building

The forty-nine-year-old bulletin *Earth and Mineral Sciences* is published by the college and circulated free of charge to alumni and other interested individuals, libraries, companies, and government agencies all over the world.

The Earth and Mineral Sciences Museum, whose beginnings date back 100 years, displays a variety of mineral specimens and other items related to the earth sciences, as well as a collection of art depicting the mineral industries. It is visited by several thousand people a year.

Geology professor works with students on a field trip.

Many Alumni Are Found in High Positions

The graduates of the college are prepared for a variety of careers in the earth and mineral sciences, entering such fields as engineering, research, production, marketing, administration, and teaching. Job opportunities are good to excellent for graduates of all the majors, and the starting salaries for several of the majors are among the highest in the country.

Alumni of the college now head or have headed such diverse agencies and companies as the U.S. Bureau of Mines, the National Weather Service, Quaker State Oil and Refining Company, Monsanto Corporation, Koppers Corporation, Carpenter Technology Corporation, the American Iron and Steel Institute, and Wheeling-Pittsburgh Steel Corporation.

For Further Information . . .

. . . on any aspect of the College of Earth and Mineral Sciences, write or phone: Dean's Office, 116 Deike Building, University Park, PA 16802; (814) 865-6546.

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stances, and microorganisms. Programs were called for to develop and implement water quality plans for agricultural and urban areas, to preserve wetlands and prime farm lands which help to reduce Great Lakes pollution, and to address local problem areas.

Much work still remains to be done, as was emphasized in the final report, but PLUARG's recommendations, if adopted by the International Joint Commission, and, in turn, implemented by the U.S. and Canadian governments, should go a long way toward maintaining a favorable water quality in the Upper Lakes (Superior and Huron) and in Lake Michigan through the turn of the century, and in helping return the lower lakes (Erie and Ontario) to a better condition. The commission, its boards, and reference groups are to be commended for their dedication to this effort.

What's more, the PLUARG study approach and the environmental management strategy development to protect water quality in the Great Lakes system should be of value to those concerned with the identification and control of nonpoint sources of pollution elsewhere in North America and the world.

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The Author

The principal interests of Dr. Richard R. Parizek, who joined Penn State's faculty in 1961, are in the hydrology of carbonate and fracture-dominated rocks; hydrological and environmental implications of mining with emphasis on coal; solid and liquid waste management using natural environmental systems; and geology applied to land-use management and decision-making. He is an original and continuing member of the Penn State living filter research team which is studying the renovation of sewage plant effluent and sludges by land application. He is co-developer of the fracture trace method for groundwater exploration using aerial photographs and remote sensing data. Last year, he was named to a National Academy of Sciences panel (WIPP) that is reviewing the high-level radioactive waste storage demonstration proposed for bedded salts near Carlsbad, New Mexico.

An example of a modern solvent extraction-electrowinning facility is this Cities Service Company's installation at Miami, Arizona. It was designed and constructed by Holmes & Narver, Inc., Orange, California, to produce 30,000 pounds of cathode copper daily. (Ray Manley photo courtesy of Holmes & Narver)

Metal Extraction—

Continued from first page

metallurgical techniques. In aqueous processing, voluminous effluent gases are replaced by smaller and more manageable aqueous streams, and the possibility exists for closed-loop operations.

Furthermore, as high-grade ore deposits continue to dwindle, it is becoming increasingly necessary to rely on low-grade ores. These materials, which often are of very complex mineralogy, cannot be treated economically by conventional, physical concentration and energy-intensive smelting techniques. For example, most of the world's nickel resources occur in land-based laterites (weathered oxide materials rich in iron and aluminum) and manganese nodules found on the ocean floor that typically contain only about 1.5 percent nickel. For such ores, the advantage of using hydrometallurgical methods of processing lies in the possibility that, by some appropriate chemical modification (e.g., roasting) of the solid feed, or by a judicious choice of leaching reagent and temperature, valuable metal can be selectively dissolved from the ore matrix, leaving the bulk of the starting material as a solid residue.

When low-grade ores are leached, the small content of metals in the ores results in dilute solutions that contain appreciable amounts of dissolved impurities. In some cases, these leach liquors contain more than one valuable metal. Thus, there is need for purification, separation, and concentration prior to production of the final products. It is in this connection that solvent extraction has now become an integral unit operation in the aqueous processing of low-grade ores.

Liquid-liquid extraction involves a chemical reaction in which a metal ion, Me^{z+}, is transferred from a water (aqueous) phase into an oil (organic) phase by means of an organic reagent, RH:

$$Me^{z+}(aq) + zRH(org) =$$
$$MeR_z\ (org) + zH^+\ (aq)$$

The forward and reverse reactions in this equation are termed extraction and stripping, respectively. In commercial applications, the extractant is used in solution with a kerosene-type diluent.

Application of solvent extraction to metals processing outside the nuclear industry became possible in the mid-sixties when General Mills Chemicals, Inc., introduced the copper-selective LIX reagents. The first commercial liquid-liquid extraction plant for copper was designed to treat aqueous solutions containing less than one gram per liter of copper and more than two grams per liter of iron. The leach solution was derived from an ore which contained 0.5 percent copper and the final product, copper cathodes, analyzed at 99.9 percent copper.[4]

The success of the LIX oxime-based extractants stimulated the development of new extractants such as Kelex 100 and Kelex 120 (Ashland Chemical Co.), SME 529 (Shell Chemical Co.), and the Acorga P5000 series (ICI, Ltd.) The similarity in the chemical composition of some of these proprietary reagents (see Figure 1) is already causing legal disputes over patent infringements.[5]

Recent developments in commercial solvent extraction have given rise to a renewed interest in the fundamental chemistry of extraction processes. Much of this research has been primarily concerned with measurements on species residing in the bulk aqueous or organic phases. It is becoming increasingly evident, however, that the interfacial region—the organic/aqueous phase boundary—deserves close attention if a comprehensive understanding of extraction mechanisms is to be gained. For example, the rate data for copper extraction by several commercial oxime reagents indicate the possible importance of interfacial rate-limiting reactions.[6] Under the sponsorship of the National Science Foundation, work is currently in progress in our laboratory here at Penn State that is aimed at elucidating the role of interfacial physicochemical phenomena in metallurgical liquid-liquid extraction processes.

The interfacial origin of rate-limiting processes in solvent extraction is not surprising since the metal ion by itself is not soluble in the organic phase, and the organic extractant is generally insoluble in the aqueous phase. In order for the metal ion and the organic extractant to react, these two species must meet each other at or near the liquid-liquid interface.

The extractants used in liquid-liquid extraction possess hydrophobic-hydrophilic molecular structures. The hydrophobic (nonpolar) portions are either aliphatic or aromatic hydrocarbons while the hydrophilic (polar) portions include functional groups such as -COOH, -OH, =NOH, =POOH, $-SO_3H$, and =NH. At the organic/aqueous interface, an extractant molecule would tend to arrange itself with its hydrophilic portion directed toward the aqueous phase and the hydrophobic group exposed to the organic side of the interface. Thus, as a result of their polar-nonpolar character, extractant molecules should be expected to exhibit (even if in a more subtle form) some of the characteristics, such as the lowering of interfacial tension, of classical surfactant molecules.

Measurements of interfacial tension have been used to calculate interfacial concentrations of extractant molecules, and some of the recent results indicate that changes in metal extraction rates obtained by varying diluent compositions can be correlated with changes in the interfacial adsorption density of extractant molecules.[6]

Interfacial effects may be especially important in mixed extractant systems involving oxime-type reagents (see Figure 1) and organic acids such as phosphoric, carboxylic, and sulfonic acids. Such reagent combinations are of both theoretical and practical interest since they can lead to synergism, i.e., extractions far in excess of those attainable with either reagent by itself.[7] Since the organic acids are generally more interfacially active than the oximes, they tend to populate the organic/aqueous interface in preference to the oxime molecules. These preferentially adsorbed acidic extractants can enhance reaction rates by acting as phase transfer catalysts.

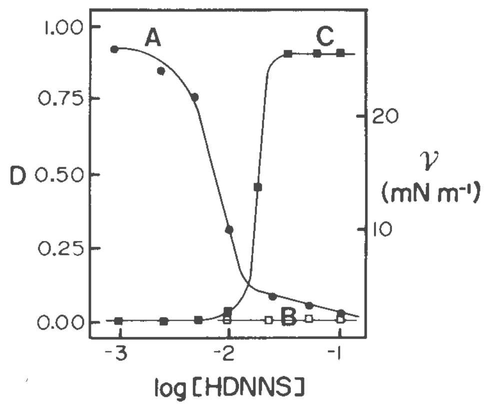

Figure 2. Micellar catalysis in the extraction of nickel with LIX63-HDNNS mixtures.[8] The effects of HDNNS concentration on: A) interfacial tension at the hexane (10^{-1} moles per liter) LIX63/water interface; B) nickel distribution coefficient, D[=(Ni(org)/Ni(aq)] for HDNNS; and C) nickel distribution coefficient for 10^{-1} moles per liter LIX63-HDNNS mixtures.

The phenomenon of phase transfer catalysis (PTC) arises from the fact that two species located respectively in two immiscible solvents can only react with great difficulty (if at all) if neither reactant is soluble in its opposite solvent. The role of the phase transfer catalyst is to transport one of the reactants across the interface into the opposite bulk phase where the desired reaction can then proceed at a more appreciable rate.

At sufficiently high concentrations, the salts of the organic acids as well as the water-wet organic solutions of the acids themselves form aggregates known as micelles. These micelles have a polar core which can solubilize considerable quantities of aqueous solution. In water-saturated solutions, a micelle consisting of 17 HDNNS (dinonylnaphthalene sulfonic acid) molecules has a core volume of about 1,650 cubic angstroms and contains as many as 50 water molecules. These micelles are capable of catalyzing metal extraction in mixed extractant systems. The presence of micellar catalysis in the LIX63-HDNNS system is illustrated in Figure 2. Curve A shows the effect of HDNNS concentration on the hexane/water interfacial tension. The change in the slope of this curve at about 10^{-2} moles per liter represents the critical micelle concentration (CMC) which marks the onset of micellization. Extraction of nickel by HDNNS alone is negligible (Curve B). In the presence of LIX63, nickel extraction is significant, but only if HDNNS micelles are also present (Curve C). The observed synergism in the LIX63-HDNNS system is related to the ability of HDNNS micelles to solubilize both LIX63 molecules (at or near the bulk organic/micelle interface) and nickel ions (at or near the micelle/aqueous core interface).[8]

If the interfacial region is as important as recent evidence suggests, implications for extraction reagent synthesis, as well as for reagent combinations and operation of commercial plants, may be far-reaching. Forty percent of the capital cost for the world's largest solvent extraction plant (Nchanga, Zambia) came from the initial solvent inventory.[1] In view of shifting patterns in the world's oil supply and the fact that solvent extraction diluents and extractants are based on petroleum feedstocks, the need to ensure the most efficient utilization of solvent extraction chemicals cannot be overemphasized.

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The Author

Dr. Osseo-Asare has three degrees from the University of California at Berkeley—B.S. in metallurgy and M.S. and Ph.D. in extractive metallurgy and mineral processing. Before joining the Penn State faculty in 1976, he worked as a project leader and research metallurgist in the extractive metallurgy laboratory of Amax, Inc., at Golden Colorado. His research interests are in the application of surface and aqueous chemistry and particulate technology to minerals processing and extractive metallurgy.

College News Notes

Three Faculty Appointees

Three new faculty members appointed recently in the college are Dr. Randolph J. Martin, associate professor of geophysics; Dr. John F. R. McIlveen, associate professor of meteorology; and Dr. James J. Reuther, assistant professor of fuel science.

Dr. Martin received his B.S. at Boston College and his M.S. an Ph.D. at Massachusetts Institute of Technology. Before coming here, he had been with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder, most recently serving as an associate professor.

Dr. McIlveen has a B.Sc. from Queen's University, Belfast, Northern Ireland, and a Ph.D. from the Imperial College of London. He came here from the University of Lancaster in England where he had been a lecturer in meteorology since 1971.

Dr. Reuther has a B.A. from the State University College at Oneonta, N.Y., and an M,A. from the State University of New York at Binghamton, N.Y., and will receive his Ph.D. in fuel science from Penn State this month.

Named AIME Honorary Member

Jesse F. Core, adjunct professor of mining engineering, was installed as an honorary member of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) at its annual meeting early this year in New Orleans, La.

There may be only 50 living such AIME members at any time, and Mr. Core was one of four men honored this year. He was cited for "his dedication and concern for the safety of all people engaged in mining, and his ability to motivate and develop leaders in the mining industry."

A 1938 Penn State mining engineering graduate, he received the University's Distinguished Alumnus Award in 1966. After being active in the mining industry for 41 years, he retired from U. S. Steel Corporation in 1977 as staff consultant on coal to the president. He had served from 1958 to 1976 as vice president for coal operations.

Rodgers Writes Book on Italy

Dr. Allan Rodgers, professor of geography, is the author of a book, *Economic Development in Retrospect: The Italian Model and Its Significance for Regional Planning in Market-oriented Economies*, published recently by Scripta/Wiley, Washington, D.C. and New York, N.Y.

Designed for geographers, regional economists, and planners, the book presents a spatial view of economic development experience in southern Italy within the broad framework of regional growth theory.

Thirty years of development practice are examined, using data derived from interviews with plant managers and government officials as well as published and unpublished government statistics, for an analysis of the growth process in southern Italy, an area termed the "Mezzogiorno." This region, Dr. Rodgers explains, has long been viewed as a classic example of subnational underdevelopment, and the study is particularly concerned with the area's evolving geographical pattern of industrialization under government planning and subsidization. The southern Italian experience is then compared with the regional development practices in other market-oriented economies in Western Europe and Anglo-America.

Dr. Rodgers has published extensively on regional development problems in Italy and the Soviet Union. This book is the product of more than three years of research in Italy that was supported by the Italian Fulbright Commission, the Guggenheim Foundation, the Cassa per il Mezzogiorno, the National Science Foundation, and the University.

Darken Honored Posthumously

Dr. Lawrence S. Darken, who retired as professor of mineral sciences in 1977, and died last June, was honored posthumously at last winter's annual meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers in New Orleans, La.

He was awarded the William Hume-Rothery Award of the Institute of Metals Division of The Metallurgical Society of AIME. This honor recognizes outstanding scholarly contributions to the science of alloys.

Dr. Darken joined the Penn State faculty in 1972 after his retirement from U.S. Steel Corp.

Alumnus Named WVU Dean

Joseph W. Leonard, who has two Penn State degrees—a B.S. in mining engineering awarded in 1953 and an M.S. in mineral preparation he received in 1958—was recently named dean of the College of Mineral and Energy Resources at West Virginia University.

Head of the WVU Coal Research Bureau since 1961, he had been acting dean of the college for the past year. He is the author of 10 books and 110 other publications and holds 24 patents. In 1969, he received the Howard N. Eavenson Award for outstanding contributions to the coal industry which is given by the American Institute of Mining, Metallurgical, and Petroleum Engineers.

Gifts to Electrical Laboratory

Two gifts were made recently by companies to the Mine Electrical Research Laboratory of the Department of Mineral Engineering.

A rectifier was received from the Ireland Mine of Consolidation Coal Company, Washington, Pennsylvania. Valued at $1,500, it will be used to supply d-c power to a shuttle car that is being used in research.

A d-c selective relaying system valued at $200 was given by Pemco Corporation, Bluefield, West Virginia. It will be used in both research and teaching.

E&MS Calendar

Folders describing the following continuing education offerings of the College of Earth and Mineral Sciences at Penn State's University Park Campus may be obtained by writing (Name of Program), Keller Bldg., University Park, PA 16802; or by phoning 814-865-7557.

Underground Mining Analysis, June 11-15.

Evaluation of Innovative Mining Equipment and Systems, June 18-21.

14th Biennial Conference on Carbon, June 25-29.

Particle Size Analysis, July 9-11.

Cooperative Mining Instructor Training, July 10-12.

Production Engineering in Underground Coal Mines, July 11-13.

Mining Professional Engineering Exam Review, July 23-27.

Modern Developments in Combustion Technology, July 23-27.

Trailing Cable Splices for Underground Mines, July 30-August 1.

Materials Transport in Mining, August 20-22.

Diesel Equipment in Underground Mines, August 27-29.

Design of Hydrology Aspects of Surface Mines to Achieve Regulation Compliance, September 10-12.

Cement Manufacturing Technology, September 10-13.

Fuel-efficient Lime Manufacture, September 13-14.

Earthquake Risk—

Continued from first page

derstand better what causes earthquakes in this part of the world.

It is widely believed that eastern United States earthquakes are the result of minor adjustments of the crust of the earth as it drifts westward over the earth's deeper interior. Earthquakes, according to this theory, occur where there are weaknesses in the rocks or along the boundaries between provinces of contrasting types of rocks. Eastern Pennsylvania lies in a diffuse belt of very minor seismicity running from Alabama to Canada along the eastern edge of the Appalachians. Large earthquakes occurred in this belt in 1755 at sea east of Boston, in 1886 near Charleston, South Carolina, and in 1929 at sea south of Newfoundland. A similar earthquake could some day occur in Pennsylvania.

The probability of such an earthquake in any given year is easily predicted, but with uncertain accuracy. It

PENNSYLVANIA EARTHQUAKES

Date		Year	Place	Mercalli Intensity
Oct.	?	1728	Philadelphia	?
Dec.	7	1737	Philadelphia	?
Oct.	30	1763	Bucks County	?
Apr.	25	1772	Delaware V.	IV
Nov.	29	1780	Bucks County	?
Nov.	29	1783	Philadelphia	IV-V
Nov.	30	1783	Philadelphia	IV
Mar.	17	1799	Philadelphia	?
Mar.	17	1800	Philadelphia	?
Mar.	29	1800	Philadelphia	?
Nov.	20	1800	Dauphin Co.	?
Nov.	29	1800	Philadelphia	IV
Nov.	12	1801	Philadelphia	?
Dec.	8	1811	Philadelphia	VII
Mar.	14	1828	Pittsburgh	III-IV
Nov.	11	1840	Philadelphia	IV
Nov.	14	1840	Philadelphia	IV
May	31	1884	Allentown	V
Mar.	8	1889	York	V
Mar.	9	1889	York	?
May	31	1908	Allentown	VI
Oct.	29	1934	Erie	V
Nov.	5	1934	NW Pa.	III
Aug.	26	1936	Mercer County	III
June	9	1937	Berks County	?
July	15	1938	Blair County	VI
Aug.	28	1938	Philadelphia	?
Apr.	2	1939	Lancaster Co.	?
Nov.	15	1939	Philadelphia	?
May	28	1940	Near Harrisburg	?
Oct.	16	1941	Centre County	?
Nov.	23	1951	Allentown	?
Jan.	7	1954	Sinking Springs (many aftershocks)	VI
Jan.	24	1954	Sinking Springs	?
Feb.	21	1954	Wilkes-Barre	VII
Feb.	23	1954	Wilkes-Barre	VI
Aug.	11	1954	Sinking Springs	?
Sept.	24	1954	Sinking Springs	?
Jan.	20	1955	Berks County	IV
Sept.	14	1961	Lehigh Valley	V
Dec.	27	1961	Pa.-N.J. Border	V
Sept.	7	1962	Fulton County	?
Oct.	10	1963	Fulton County	?
Feb.	13	1964	Blair County	V
May	12	1964	Cornwall	VI
Dec.	7	1972	Lancaster Co.	V
Feb.	28	1973	NJ & Phila.	V-VI
July	16	1978	Lancaster Co.	IV-V
Oct.	6	1978	Lancaster Co.	V

Where intensity is not listed, it was small. Principal sources: U.S.C.G.S. and Dominion Observatory lists, H. Landsberg, R. W. Stone and L. Winkler.

turns out to be small, but not zero. The basis of such a prediction is the same theory used to predict big floods from the past frequency of smaller floods. The theory of predictions of extreme events was developed by an Austrian, E.J. Gumbel. It requires only that individual events be independent of one another and random in time, and that their frequency decrease exponentially with their size with no upper limit. It is not certain that all these conditions apply to earthquakes, but they seem to.

To use Gumbel's theory, it is first necessary to measure the size of the largest earthquake to have affected a region in each of a sequence of years. For our purpose here, we will use Mercalli intensity, which is a scale designed to measure the degree of damage produced by an earthquake. (Do not confuse this scale with the Richter scale, which is used to measure earthquake energy, and requires that the earthquake be recorded by seismographs.)

Mercalli intensity runs from zero (not felt) to XII (total destruction). Intensity V on the scale is the threshold of the cracking of plaster, VII the threshold of significant structural damage to buildings, IX to foundations. An earthquake of intensity VIII is potentially serious if it occurs in a heavily populated area such as most of Pennsylvania. Earthquakes of intensity III or smaller can easily occur without being reported.

Between 1927 and 1976, two earthquakes of intensity VI and one of intensity V occurred within 50 kilometers (31 miles) of the city of Lancaster: one in 1954 near Sinking Spring in Bucks County, one in 1964 near Cornwall, Lebanon County, and the smallest in 1972 near Lancaster itself. In twenty-five additional years, earthquakes of such strength occurred in surrounding areas that it is calculated that they should have been observed with intensity III or greater within 50 kilometers of Lancaster. In the other twenty-two years, either no earthquakes were felt or they were of lower intensity than III.

By rearranging the intensities of these annual-maximum earthquakes from smallest to largest and plotting them on "probability" paper, they can be seen to lie very nearly along a straight line as shown in Figure 1. The horizontal scale in this graph is such that, if the assumptions required for Gumbel's theory to apply are met, the points should lie close to a straight line and there is a 95% probability that points will lie between the two lines shown, as all but one do.

The upwards projections of these two lines can be used to predict the average return periods of larger events than have actually occurred to date. For instance, the graph predicts that an intensity VIII earthquake (i.e., a serious earthquake) might occur once in between 240 and 550 years, and that once in 1000 years, one might expect an earthquake of intensity IX. This is a very low level of seismic risk.

Figure 2 is a similar graph for the Philadelphia area. The hazard here appears to be slightly larger, but with substantially greater uncertainty. Earthquakes are so rare in western Pennsylvania that it is difficult to develop a graph of this sort for Pittsburgh.

These curves should not be interpreted to indicate that a large earthquake of the size predicted will occur in the future, only that this is as often as one is likely to occur. Various factors make these predictions more likely to exaggerate the hazard than to underestimate it. For instance, it is known that for some areas the curves tend to flatten toward the right. It is entirely possible that this is the case for Pennsylvania. (Note that the points for Philadelphia exhibit a tendency to curve in this fashion). To detect such flattening, more accurate observations of earthquake intensities are needed. Also, the intensities plotted in Figures 1 and 2 are in many cases estimated from epicentral intensities and average attenuation rates with distance. Actual intensities for some of these events may have been less. Research on this problem is proceeding at Penn State.

Pennsylvanians can be thankful that they live in one of the safest states in the United States from the point of view of risk from earthquakes.

The Author

Dr. B. F. Howell, Jr., who also serves as associate dean of the Graduate School, received his A.B. at Princeton University, and his M.S. and Ph.D. at the California Institute of Technology. He joined the Penn State faculty in 1949 as associate professor of geophysics and chief of the then Division of Geophysics and Geochemistry. He was previously employed by the University of California (1942-45) and the United Geophysical Company (1946-1949). His research has been largely in seismology and the physical properties of rocks. He has been interested in earthquake prediction and risk since studying seismology under C. F. Richter, the man for whom the widely used earthquake magnitude scale is named. For the March 1973 issue of this bulletin, he wrote an article entitled "Earthquake Hazard in the Eastern United States."

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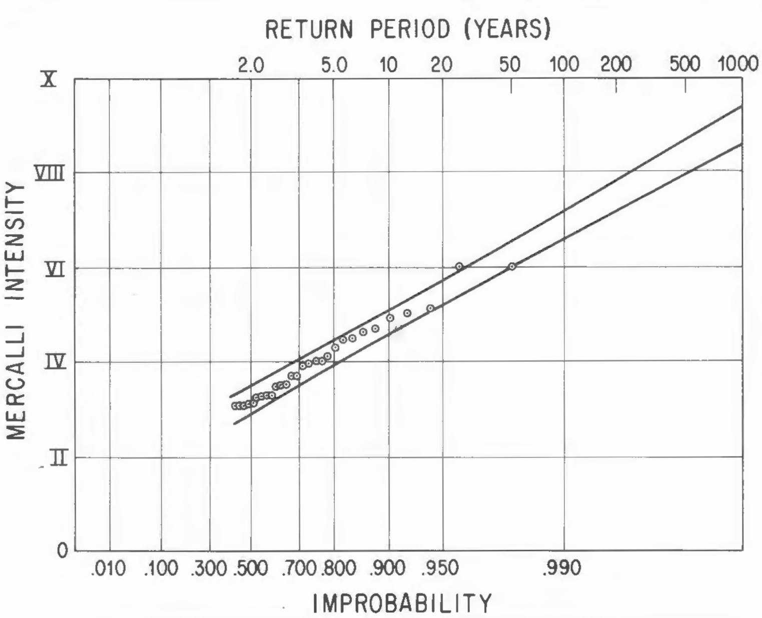

Figure 1. Earthquake recurrence expectation within 50 km (31 miles) of Lancaster, Pennsylvania. Lines encompass 95 percent probability. Data points are largest 1927-1976 earthquakes of intensity greater than III.

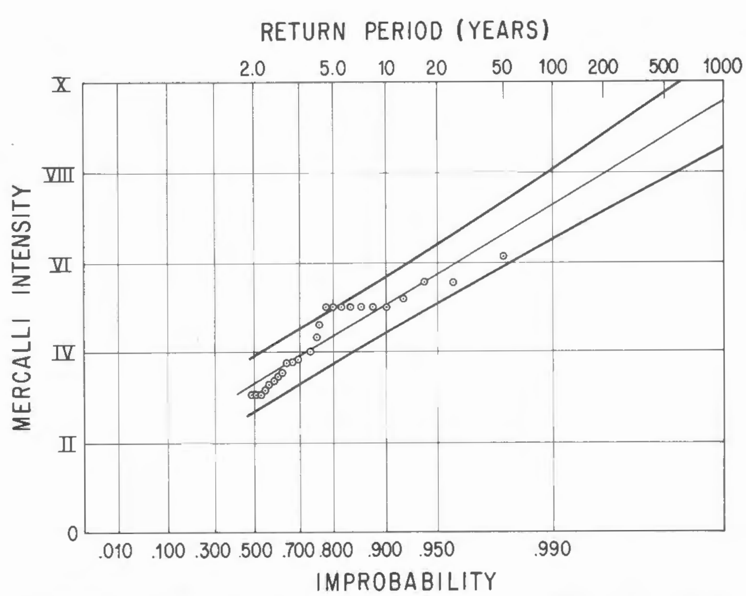

Figure 2. Earthquake recurrence expectation within 50 km (31 miles) of Philadelphia, Pennsylvania. Lines encompass 95 percent probability. Data points are 1927-1976 earthquakes of intensity greater than III.