

GEOLOGICAL SURVEY CIRCULAR 768



**Proceedings of the Geology and
Food Conference, with Related
U.S. Geological Survey Projects
and a Bibliography**

Proceedings of the Geology and Food Conference, with Related U.S. Geological Survey Projects and a Bibliography

By Omer B. Raup, *Editor*

Bibliography compiled by Flora K. Walker

G E O L O G I C A L S U R V E Y C I R C U L A R 7 6 8

United States Department of the Interior
CECIL D. ANDRUS, *Secretary*



Geological Survey
V. E. McKelvey, *Director*

Library of Congress catalog-card No. 77-600060

Free on application to Branch of Distribution, U. S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202

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PROCEEDINGS OF THE GEOLOGY AND FOOD CONFERENCE, WITH RELATED U.S. GEOLOGICAL SURVEY PROJECTS AND A BIBLIOGRAPHY

By Omer B. Raup, Editor

Bibliography compiled by Flora K. Walker

PURPOSE AND ORGANIZATION OF THE GEOLOGY AND FOOD CONFERENCE

Food production is a major factor in the national economy, both in terms of domestic consumption and foreign export. Modern intensive agricultural practices have strained the production capacity of the Nation's agricultural lands and constitute a major geologic process changing the geochemical and physical properties of the land surface. As a result, the environmental quality and agricultural productivity are threatened. In addition, rapid exploitation of fertilizer-mineral deposits coupled with withdrawal of fertilizer mineral-bearing lands for environmental reasons has placed our domestic supply of fertilizer minerals in jeopardy. It is, therefore, vital to the social and economic needs of the Nation to have a program focused on the geologic factors that relate to intensifying the agricultural productivity of the land.

The U.S. Geological Survey has a number of projects in progress which contribute directly or indirectly to the agricultural needs of the Nation. Five projects are devoted to the study of the geology and geochemistry of phosphate, one of the major components in fertilizer. Six other projects concern various aspects of some of the other fertilizer minerals, such as potash, nitrates, and sulfur. Several projects are devoted to studies of trace elements in soils, regional geochemistry, and environmental and land-use mapping, all of which

apply directly or indirectly to the solution of problems that have application in the general field of agriculture.

At the request of the Chief Geologist, a conference was organized to investigate areas in which the U.S. Geological Survey might increase its research activities to make a greater contribution to the field of agriculture. The conference, entitled "Geology and Food," was held January 22-24, 1975, in the Building 25 Auditorium at the Denver Federal Center. Presentations were made by 24 U.S. Geological Survey personnel. The following is a list of the speakers and their papers, arranged by category:

Richard P. Sheldon, Chief Geologist — Introductory remarks.

FERTILIZER MATERIALS

- Alfred J. Bodenlos — Soil sulfur—Requirements, deficiencies, and replenishment.
James B. Cathcart — Distribution and resources of phosphate in the eastern United States and in Latin America.
James B. Cathcart — Environmental and cultural problems related to phosphate mining and processing.
David F. Davidson and Richard P. Sheldon (speaker) — The geographic and geologic distribution of phosphate deposits.
Walter G. Dupree, Jr. — Fertilizer demand—Domestic and worldwide.
George E. Erickson — Geology, resources, and development potential of naturally occurring nitrates.
Robert J. Hite — A geochemical success story in northeast Thailand.
Robert J. Hite — Phosphate and evaporites—A direct relationship?
Charles L. Jones — Potash resources and economics.

- Keith B. Ketner — Nature of the Phosphoria sea and the relation of upwelling to rich phosphate deposits.
 Richard F. Meyer — Energy requirements of the agriculture industry.
 Richard P. Sheldon — Upwelling model and its applications.

SOIL AMENDMENT MATERIALS

- Alfred L. Bush — Distribution of volcanic rocks potentially useful as soil amendments.
 Cornelia C. Cameron — Peat as a soil amendment.
 Harold A. Hubbard and George E. Erickson (speaker) — Limestone and dolomite in agriculture.
 Ronald C. Severson — Soil amendments and physical properties of soils.
 Richard A. Sheppard — Potential role of natural zeolites in agriculture and animal husbandry.
 Vernon E. Swanson — Humate as a soil additive.
 Ray E. Wilcox — Volcanic ash and related materials as soil amendments.

WEATHERING OF ROCKS, SOILS, TRACE ELEMENTS, AND PLANT NUTRITION

- Helen L. Cannon — The importance of elemental interrelationships in biological systems.
 T. T. Chao — Soil chemical properties and plant nutrient availability.
 Wallace R. Griffiths — Problems of lateritic soils.
 Hansford T. Shacklette — Major nutritional elements in soils and plants—A balance sheet.
 Ronald R. Tidball — Composition as a measure of soil quality.
 Richard W. White — Weathering, and the parent materials of soils.

RELATED STUDIES

- Simon Cargill — Computer-based data systems for fertilizer materials.
 Roger B. Morrison — How remote sensing can assist in mapping surficial and fertilizer materials.
 Robert D. Watson — Phosphate rock detection using solar-stimulated luminescence.

Eleven guests from industry, universities, and other Government agencies were invited to attend the conference. They were requested to discuss the papers and participate in the workshop sessions. The following is a list of the invited participants:

- Joseph Coffman, U.S. Bureau of Mines, Spokane, Wash.
 G. Donald Emigh, Monsanto Industrial Chemicals Co., St. Louis, Mo.
 Donald L. Everhart, International Minerals and Chemical Corp., Libertyville, Ill.
 Leonard Garrand, Garrand Corporation, Salt Lake City, Utah.
 Ray Gremillion, Tennessee Valley Authority, Muscle Shoals, Ala.
 Tommie Holder, Soil Conservation Service, Denver, Colo.

- Clifford Holmes, Phillips Petroleum Co., Bartlesville, Okla.
 Robert B. Kayser, International Minerals and Chemical Corp., Libertyville, Ill.
 Albert E. Ludwick, Colorado State University, Fort Collins, Colo.
 Guerry McClellan, Tennessee Valley Authority, Muscle Shoals, Ala.
 Sterling R. Olsen, U.S. Department of Agriculture, Agricultural Research Service, Fort Collins, Colo.

The conference was organized into three parts:

1. Presentation of papers by U.S. Geological Survey personnel in the following subject areas—fertilizer materials; soil amendment materials; weathering of rocks, trace elements, and plant nutrition; and related studies.
2. The invited participants were requested to give their reactions to the research that was reported on in the papers and to make any other comments that they felt were appropriate. In addition, they were asked to answer the question, "What could or should the USGS do that would aid the agricultural industry?"
3. The speakers and invited participants were divided into two major study groups. These constituted the workshop sessions on (a) fertilizer materials, and (b) soil amendments and rock weathering. The workshops met for about 6 hours. These sessions were followed by a report from the chairman of each workshop in which he gave a consensus of the recommendations of the group.

ABSTRACTS

INTRODUCTORY REMARKS

By Richard P. Sheldon

A proper objective for man is to feed himself adequately without getting the world ecology out of balance now or in the future.

But we are a long way from achieving this rather utopian objective, which in fact has never been achieved in the past and may be unachievable in the future. Certainly the recent famine in the Sahel and the present one in India and Bangladesh are evidence of the failure of the present system, and a great apprehension exists today about man's future ability to feed himself.

Obvious factors contributing to this crisis are population growth, limited farm land, and lack of fertilizer and water. Some of the not-so-obvious factors are the following:

1. Low productivity of existing farms.

2. Inadequate food distribution.
3. Loss of food to pests.
4. Misallocation of food.
5. Pollution from intensive farming technology.
6. Energy requirements of intensive farming technology.
7. Loss of soil through erosion.

It would appear that man is on the brink of a major change in his way of producing his food.

What can geologists do to impact this problem which seems largely biologic and is in an area where we have played a relatively minor role in the past?

I would propose that the science of geology can contribute in some degree to the following objectives:

1. Increase in arable acreage by land reclamation.
2. Optimum agricultural use of ground and surface water.
3. Adequate supply of fertilizer and soil-amendment raw material.
4. Understanding of the geochemical and geologic processes operating within a balanced ecologic system.
5. Projection of the mineral resource supply to which the agricultural system must adjust in the long term.

The next question is, "What can the USGS do to contribute in solving this national and world problem?"

That is the purpose of this conference.

FERTILIZER MATERIALS

SOIL SULFUR—REQUIREMENTS, DEFICIENCIES, AND REPLENISHMENT

By Alfred J. Bodenlos

Sulfur is one of the 11 elements essential to life; it is needed specifically in the synthesis of proteins, vitamins, enzymes, and, indirectly, chlorophyll. Both plants and animals contain about as much sulfur as phosphate, and the ratio of nitrogen to sulfur should be 15:1 to insure adequate synthesis of proteins.

Notwithstanding, soils in parts of most of our States and in parts of Canada, Japan, western Europe, Australia, New Zealand, South America, and Africa do not contain sufficient sulfur to achieve maximum crop yields or protein content; and this in turn results in reduced yields of meat,

wool, and milk. These deficiencies can result from a variety of causes: excessive leaching of soils due to heavy annual rainfall or to the high porosity of the soils themselves; intensive agriculture or poor livestock management; insufficient replenishment of sulfur from natural rock weathering or atmospheric fallout; or use of low-sulfur fertilizers.

Sulfur resources are globally widespread, occurring as elemental deposits in evaporites and in volcanic terrain, as gypsum and anhydrite, as sulfide-bearing metallic minerals, and as organic and inorganic compounds in most fossil fuels; Africa is the only continent that seems to have limited resources of sulfur-bearing rocks, minerals, or fuels. Yet most sulfur, either in elemental form or as pyrite, is produced from mines or recovered as a byproduct from base-metal smelters, oil refineries, or gas processing plants located in the industrialized nations; therefore, most of those countries should have sufficient resources of sulfur and sulfur-bearing materials to permit adequate fertilization to compensate for deficiencies in soil sulfur. Providing adequate sulfur to the agricultural belts of the less-developed nations will be more difficult because of problems involving economic factors and deficiencies in the infrastructures needed to move large tonnages of sulfur-bearing minerals or chemicals from local sources to the cultivated segments of such countries.

Sulfur is used in the processing of phosphate rock in addition to its use as an essential element in fertilizers. Sulfur, in the form of sulfuric acid, is used to acidulate phosphate rock into phosphoric acid which is the soluble form necessary for fertilizer manufacture. More than half the sulfur annually consumed in the United States has one of those two uses. Sulfur compounds also are indispensable in neutralizing the alkaline soils of arid regions and in increasing their porosity.

DISTRIBUTION AND RESOURCES OF PHOSPHATE IN THE EASTERN UNITED STATES AND IN LATIN AMERICA

By J. B. Cathcart

Phosphate deposits of igneous origin, those derived from guano, and phosphorites of sedimentary origin are widespread in the Eastern United States and in Latin America. About 75 percent of the production of phosphate is from sedimentary

phosphate deposits, 20 percent from igneous apatites, and the remainder from guano. Production in the United States in 1974 was 44.7 million short tons—all but a trace from sedimentary phosphorites.

Reserves and resources in metric tons in the Eastern United States and in Latin America are as follows:

| Reserves | | Resources |
|-------------------------|-----------------------|----------------------------------|
| Eastern United States | | |
| Guano or guano-derived | None | Tens of thousands |
| Igneous apatite | Hundreds of thousands | Millions |
| Secondary | Tens of millions | Hundreds of millions |
| Sedimentary phosphorite | Billions | Hundreds of billions |
| Latin America | | |
| Guano or guano-derived | Tens of millions | Millions |
| Igneous apatite | Hundreds of millions | Hundreds of millions or billions |
| Secondary | None | None |
| Sedimentary phosphorite | Hundreds of millions | Billions |

Phosphate deposits and occurrences in these areas are summarized in tables 1 and 2.

TABLE 1. — *Phosphate deposits of the Eastern United States*

[Leaders (..) indicate no data]

| State | Area | General geology | Reserves (metric tons) | Resources (metric tons) |
|---|---|--|-----------------------------------|---|
| Sedimentary phosphates | | | | |
| Florida | Polk, Hillsborough Counties | Tertiary; Atlantic Coastal Plain; Miocene or, in younger rocks, reworked from Miocene. | 600×10^6 | 1000×10^6 |
| | Hardee, Manatee, DeSoto Counties | Turbulent mixing on flanks of rising domes; phosphate pellets in sand, clay, limestone; may be reworked, concentrated, enriched in marine or continental environment; pellets contain as much as 38 percent P_2O_5 . | 300×10^6 | 1000×10^6 |
| | Hamilton, Alachua, Lake, Orange; and | | 100×10^6 | $>800 \times 10^6$ |
| Georgia | Lowndes, Echols Counties | | | |
| Florida, Georgia, South Carolina. | Throughout peninsular Florida in coastal plain to South Carolina. | Hawthorn Formation; Miocene; phosphate pellets in limestone and marls; pellets contain 20–30 percent P_2O_5 . | None | $>100 \times 10^6$ (pellets). |
| Georgia | Savannah River at Atlantic Ocean. | Hawthorn Formation (Miocene) and Duplin Marl (Pliocene); phosphate pellets in sand, clay, marl; pellets contain 30 percent P_2O_5 . | None | $>1.6 \times 10^9$ (pellets). |
| South Carolina | Beaufort County | do. | None | Hundreds of millions (pellets). |
| North Carolina | Beaufort County | Pungo River Formation; Miocene; phosphate pellets in sand, clay, marl; pellets contain 30 percent P_2O_5 . | 1×10^6 tonnes of pellets | 10×10^6 (pellets). |
| Other occurrences of phosphate pellets and nodules are in the Eocene Castle Hayne Limestone of North Carolina, the Eocene Tallahatta Formation of Georgia, and the Oligocene Cooper Marl of South Carolina. | | | | |
| Alabama, Georgia, Mississippi. | Widely distributed in several counties. | Cretaceous; several formations of limestone, chalk, marl, containing phosphate pellets and nodules; pellets may have 30 percent P_2O_5 , rock only about 3 percent. | None | No data; could be very large, but tonnes per unit area too small to be minable. |
| Oklahoma, Kansas, Missouri. | Eastern Oklahoma, Kansas, and adjacent western Missouri. | Pennsylvanian; phosphate pellets and nodules in shales interbedded with limestone; several phosphate-bearing shales; nodules are 30 percent P_2O_5 , shales 2–3 percent. | None | Do. |

TABLE 1. — *Phosphate deposits of the Eastern United States* — Continued

| State | Area | General geology | Reserves (metric tons) | Resources (metric tons) |
|---|--|---|--------------------------------------|---|
| Sedimentary phosphates — Continued | | | | |
| Texas | Llano uplift | Morrowan; sandy, calcareous phosphorite at base; may be lag gravel; phosphorite contains 10–15 percent P_2O_5 . | None | $>40 \times 10^6$ |
| Arkansas | Northwestern part of State. | Pitkin Limestone (Mississippian) and Hale Formation (Mississippian); lenticular beds of calcareous phosphorite at base of Hale Formation; some mining in past, started again in 1975. | 5×10^6 | Several times the reserves, but still limited; millions. |
| | | Mississippian; Fayetteville Shale; beds of shale may contain as much as 6 percent P_2O_5 ; pelletal; content of pellets not known; may be an area of upwelling. | None; too low grade. | No data, but in aggregate may be large, billions(?). |
| Alabama, Georgia, Tennessee, Kentucky, Ohio, Indiana. | Various counties in contiguous States. | Devonian and Mississippian Chattanooga and New Albany Shales and Mississippian Maury Shale; contains sparse phosphate nodules; nodules as much as 30 percent P_2O_5 , shale beds 2–3 percent. | None; too few nodules per unit area. | No data, but probably billions of tonnes of nodules throughout the very extensive outcrop belt. |
| Arkansas | Northwestern part of State, into Oklahoma(?). | Devonian; Sylamore Sandstone Member of Chattanooga Shale; some phosphate in basal sandstone. | None | No data, small(?). |
| Tennessee | Perry, Maury, Lewis, Hickman Counties. | Devonian; Hardin Sandstone Member of Chattanooga Shale contains phosphate pellets reworked from underlying Ordovician rocks; so-called "blue rock"; mined in the past; thin, as much as 25 percent P_2O_5 . | None; mining problems. | 80×10^6 ; may be greater. |
| New York, Pennsylvania, Virginia | Central New York, South-Central Pennsylvania, Southwest Virginia | Devonian; Oriskany Sandstone; base is sandy phosphorite; thin beds as much as 25 percent P_2O_5 . | None | No data; may be some tens of millions of tonnes. |
| Minnesota | Twin Cities area | Ordovician; lag gravels at base of Decorah Shale and Galena Dolomite. | None | Probably small. |
| Iowa, Wisconsin, Illinois. | In the Tri-State area. | Ordovician; Maquoketa Shale; thin beds at base of Maquoketa contain as much as 15 percent P_2O_5 ; sandy phosphorite. | None; mining problems. | 8×10^6 t of rock near Dubuque that could be stripped; total is probably much larger. |
| Arkansas | Independence, Izard Counties. | Ordovician; Cason Shale; phosphate nodules and pellets in shale; thin beds (1+ m) contain as much as 20 percent P_2O_5 ; on southern flank of rising Ozark dome. | do | 20×10^6 t; may be much more; tonnage estimated from outcrop area plus few cores. |
| Tennessee | Nashville Basin | Ordovician; phosphatic limestone of several formations deposited on west flank of rising Nashville dome; turbulent mixing of laterally moving currents at an optimum water depth. | None; too low phosphate content. | $3-5 \times 10^9$; average about 5 percent P_2O_5 . Source rock for the "brown rock" deposits. |
| | Sevier, Polk Counties. | Precambrian; Ocoee Supergroup; lenticular beds of pelletal phosphate associated with shale and limestone; beds as much as 1.3 m thick; contain as much as 35 percent P_2O_5 . | None | No data; probably small in individual deposits; may be large in total. |
| Michigan | Marquette and Baraga Counties. | Precambrian X (middle); large phosphate nodules in siliceous slaty conglomerate; one 15-m bed contains 15 percent P_2O_5 ; oldest phosphorite known in the United States. | None, too little known. | May be large. |
| Secondary deposits of phosphate rock | | | | |
| Tennessee, Alabama, Kentucky. | Nashville basin and adjacent areas both north and south. | Residual; "Brown rock"; acid weathering in modern cycle of Ordovician phosphatic limestone; calcite removed; residually concentrated apatite. | Tens of millions. | About same as reserves. |
| Tennessee | Johnson, Perry Counties. | Phosphatized rock; "White rock"; phosphate, leached by acid ground water; replaces underlying carbonate rock. | None; mining problems. | Tens of millions. |
| Florida, Georgia. | Many counties | "Hardrock." Origin same as above | do | Tens to hundreds of millions. |
| Florida | Several counties | Aluminum phosphate; wavelite, crandallite; formed by leaching of phosphate by acid water; phosphate combines with alumina of clay minerals. | None; processing problems. | 100×10^6 . |
| Florida, Georgia, South Carolina. | Many counties | Reworked; "River pebble"; phosphate, eroded by modern rivers from marine phosphorites, is concentrated as bars and in the flood plains of the rivers. | None; mining problems. | Millions. |

TABLE 1. — *Phosphate deposits of the Eastern United States* — Continued

| State | Area | General geology | Reserves (metric tons) | Resources (metric tons) |
|---|---------------------------|---|--|--------------------------------|
| Apatite deposits of igneous origin | | | | |
| New York, New Jersey, Massachusetts. | Adirondacks | Magnetite-apatite marginal differentiates | Nil | Small; in individual deposits. |
| Virginia | Amherst, Nelson Counties. | Ilmenite-apatite veins or disseminations | None | Tens to hundreds of thousands. |
| Missouri | Pea Ridge | Intrusive sheets; high phosphorus iron ore, apatite concentrated in processing byproduct, may amount to 100,000 metric tons per year. | Hundreds of millions of tons of iron ore that contain about 4 percent apatite. | |
| Arkansas | Magnet Cove | Carbonatite; apatite-rich in places | Nil | Small, probably. |
| Guano or guano-derived | | | | |
| Florida | Monroe | Pellets, in bird rookery, derived from guano | Nil | Very small. |

TABLE 2. — *Phosphate deposits of Latin America*

| Country | Area | General geology | Reserves (metric tons) | Resources (metric tons) |
|---|------------------------|--|--|--|
| Sedimentary Phosphorite | | | | |
| [No phosphate deposits are known in Argentina, Bolivia, and Ecuador, but all have reported sedimentary beds that contain minor amounts of P_2O_5 . Consequently, potential exists for marine phosphorite deposits in beds of Cretaceous and Tertiary age. There are reports of Ordovician phosphate in Argentina] | | | | |
| Mexico | Zacatecas | Jurassic; La Caja Formation; calcareous phosphorite; marine; miogeosyncline; best is 5–7 m thick, as much as 20 percent P_2O_5 . | 150×10^6 , >13 percent P_2O_5 . | 130-km ² area; folded, faulted; total resources probably billions. |
| | Baja California | Miocene; Monterey Formation; siliceous phosphorite; platform facies; 80 km strike; best is 2–m thick, 19 percent P_2O_5 . | None | Probably hundreds of millions. |
| | | Modern beach sand; probably reworked Miocene; 80 km long; 3 percent P_2O_5 . | None | $500-1000 \times 10^6$. |
| Nicaragua | Cerro Papayal | Phosphatic sandstone; as much as 25 percent P_2O_5 , in small pocket of sediments on volcanics. | None | No data; may be moderate. |
| Panama | Specific area unknown. | Very sparse data; horizontal phosphate beds reportedly uncovered in road building. | None | ? |
| Colombia | Cordillera Oriental. | Cretaceous; shelf facies is sandy; miogeosynclinal facies is calcareous; Plaeners and La Luna Formations; beds as much as 5 m thick, average about 20 percent P_2O_5 . | 100×10^6 | 500×10^6 indicated; total probably billions. |
| Venezuela | Tachira | Cretaceous; La Luna Formation; extension of deposits in Colombia. | 1×10^6 | Tens of millions plus |
| | Falcon | Miocene; secondary (?) very similar in appearance to hardrock of Florida. | 15×10^6 | Unknown — not large (?) |
| Brazil | Near Recife | Cretaceous; Gramame Formation; pelletal phosphate 20 cm to 4 m thick at base limestone of Gramame; total area underlain by the Gramame Formation is 100×12 km. | 50×10^6 | May be billions from total area of the formation; no data. |
| | Minas Gerais | Precambrian Bambui Group; lenticular isoclinally folded phosphorite bodies, as much as 80 m thick in shales of Bambui. | 300×10^6 | 700×10^6 . |
| Peru | Central | Jurassic; Aramachay Formation; miogeosynclinal phosphorite in limestone, mudstone; as much as 17 m thick; 10 percent P_2O_5 . | None | May be very large; phosphate beds crop out over 100 km; folded and faulted sequence. |
| | Northern | Cretaceous; Muerto Formation; phosphatic limestone, reported to be tens of meters thick with 5 percent P_2O_5 . | None | May be large. |
| | Sechura | Miocene; Zapayal Formation; pelletal phosphorite beds in clay, sand, and diatomaceous clay; best bed is 1.3 m and 23 percent P_2O_5 . | 500×10^6 | 900×10^6 . May be much larger. Tonnages computed for "best" material. |
| Apatite deposits of igneous origin | | | | |
| Brazil | Widespread | Carbonatite bodies contain apatite at Araxa, Jacupiranga, Catalão, Tapira, Serrote, and elsewhere. | 100×10^6 | Many carbonatite bodies are being investigated. Resources are many times reserves. |
| | Bahia | Pegmatite apatite; may be thoroughly metamorphosed sediments of Precambrian age. | None | Millions. |

TABLE 2. — *Phosphate deposits of Latin America* —Continued

| Country | Area | General geology | Reserves (metric tons) | Resources (metric tons) |
|---|-----------------------|---|---------------------------|----------------------------|
| <i>Apatite deposits of igneous origin — Continued</i> | | | | |
| Chile | Coquimbo and Atacama. | Apatite associated with magnetite in dikes or local intrusives. | Limited | Small. |
| <i>Guano or guano-derived deposits</i> | | | | |
| Dutch Antilles | Curacao | Guano-derived P_2O_5 replaces underlying coral limestone; 68,000 metric tons to the United States (1974). | 30×10^6 | No data. |
| | Aruba | Guano-derived P_2O_5 replaces igneous rocks; high Fe and Al. | None | 14×10^6 . |
| Antigua | Redonda Island | Guano-derived P_2O_5 replaces igneous rocks. | None | Limited. |
| Brazil | Trauíra Island | Guano-derived P_2O_5 replaces bauxite. | | 10×10^6 . |
| Colombia | Malpelo Island | Guano-derived P_2O_5 replaces igneous rocks. | | 0.4×10^6 . |
| Chile Peru | Coastal areas | Bird guano deposits; mined for local use; amount mined depends on amounts formed by birds. | Small | "Renewable;" small. |

ENVIRONMENTAL AND CULTURAL PROBLEMS RELATED TO PHOSPHATE MINING AND PROCESSING

By James B. Cathcart

Environmentalists, ecologists, and other groups of concerned citizens whose aim is to protect the environment view with alarm the damages that may result when mining and chemical or mineral processing plants are proposed for the areas in which they live. No mention is ever made of the benefits that will accrue to individuals and to society as a result of the mining and processing. The case for phosphate mining is particularly clear—without phosphate fertilizer, which has to be made from rock phosphate, food production as we know it today would be impossible.

Open-pit mining unquestionably alters and upsets the environment and the ecology while it is going on. However, land can be reclaimed, upsets to the ecology can be minimized, and, a few years after mining, the land can be returned to almost any use that can be envisioned.

In Florida, land is being reclaimed, and, after reclamation, it is better farmland than prior to mining. Reclaimed land is being used for recreation—boating, swimming, fishing—and outdoor sports—golf, baseball, and so forth; some land is used for housing developments and for industrial parks, and some is used as wildlife refuge. The mess made by mining is no longer visible; the land is utilitarian and also attractive to the eye.

A great fear of many people is that their potable water supplies will be permanently damaged by mining. In Florida, evidence exists that this is not

so and that, after mining is completed, the water supplies return approximately to the pre-mining state within a few score years.

Air and water effluents from mining and processing plants must be purified, so that deleterious elements do not get into the environment. State and Federal laws require that only relatively pure water and air are returned to the environment, and Florida producers are spending millions of dollars per year to meet these requirements. These efforts must be continued and improved not only in Florida but throughout the country, wherever open-pit mining is done.

Phosphate mining must continue or our food supplies will be drastically reduced, and there must be a strong effort by industry and government to show the environmentalists and the public at large that production of minerals and their processing can be accomplished with only minimal damage to the environment. As a corollary to this, strong efforts should be made by industry to see that air and water pollution are minimized and that the land is returned, after mining, to a usable state. Compromises will have to be made by both sides. It is not possible to return land to its original state after mining and it may not be possible to meet too rigid standards of air and water pollution, but that should not deter both sides from seeking a reasonable compromise which insures maximum production with minimum disruption.

THE GEOGRAPHIC AND GEOLOGIC DISTRIBUTION OF PHOSPHATE DEPOSITS

By David F. Davidson
and Richard P. Sheldon

Phosphate resources of the world are large and are widely distributed both geographically and stratigraphically.

Guano and apatite deposits probably will not bulk large in the production picture for the foreseeable future—most production will continue to come from deposits of marine phosphate rock. The already identified resource of such deposits appears to amount to tens of billions of tons.

Large resources have been identified in rocks of Phanerozoic age, but much further work must be done to make a realistic appraisal of these resources. Such an appraisal should lead to development of new ideas to be used in the search for so far unknown deposits.

FERTILIZER DEMAND— DOMESTIC AND WORLDWIDE

By Walter G. Dupree, Jr.

Two of the three main fertilizer materials—nitrates, potash, and phosphates—are experiencing short-run supply problems. The nitrates and phosphates will be in short supply from the present until 1980, while potash will have surplus capacity.

In the long run, potassium (from potash) in the United States is expected to increase in consumption from 4 to 12 million metric tons. Phosphorus (from the phosphates) is expected to increase in consumption from 4 to 12 million metric tons, while nitrogen (from natural gas) consumption will increase from 18.7 to 60.6 million metric tons.

The greatest fertilizer problem in the United States will be related to phosphates owing to the increasing number of constraints placed on its development in the United States. The conclusions are as follows:

1. An enhanced resource evaluation program is necessary.
2. A research program for increasing yields from phosphatic raw materials is necessary.
3. Rationalization of local, State, and Federal constraints is necessary.

GEOLOGY, RESOURCES, AND DEVELOPMENT POTENTIAL OF NATURALLY OCCURRING NITRATES

By George E. Ericksen

The sources and uses of fixed nitrogen chemicals have changed dramatically during the past three decades, chiefly because of a phenomenal growth in the use of synthetic nitrate fertilizers. Chilean nitrate deposits, which furnished nearly all of the world's fixed nitrogen in the late 19th and early 20th centuries, yielded only about 0.25 percent of fixed nitrogen supplies in 1970. In 1940, world consumption of fixed nitrogen products, used largely as fertilizer and munitions, was about 1 million metric tons of contained nitrogen. About 25 percent was supplied by the Chilean deposits. In 1970, world production was nearly 39 million metric tons of contained nitrogen (about 80 percent used as fertilizer), of which Chile contributed only 100,000 metric tons. On the basis of present growth rates, projected world consumption will be about 165 million metric tons in the year 2000. The Chilean contribution in 2000 will probably be less than in 1970 unless new technology is devised and the Chilean nitrate industry is broadened to recover other saline components, such as lithium, magnesium, sulfate, chloride, perchlorate, and borate, in the nitrate salts of ore. In the early 1970's, the only components being recovered were sodium and potassium nitrate and iodine.

Naturally occurring nitrate deposits include caliche layers and playa deposits in desert environments, cave deposits and field efflorescences due to action of nitrifying bacteria on animal wastes, and sea bird guano in coastal desert environments. With the exception of the Chilean caliche deposits, the resources of all naturally occurring nitrate deposits are insignificant in terms of world consumption. In addition to the Chilean deposits, caliche deposits are known to exist in other deserts—for example, Death Valley, Calif.—but none is of commercial grade and size. The possibility of finding commercial deposits outside of Chile is remote. Prior to the 20th century, cave deposits and animal wastes were sources of potassium nitrate for manufacture of gun powder. Cultivation of animal wastes to promote nitrification by bacteria yielded important quantities of nitrate until the mid-19th century when Chilean production became dominant. However, India con-

tinued to produce potassium nitrate from animal and human wastes well into the 20th century.

The nitrate deposits of northern Chile are part of the saline complex of the Atacama Desert, a saline desert that is more arid than most, if not all, other deserts of the world. The nitrate deposits are in a region nearly 700 km long, mainly along the eastern border of the Coastal Range but also within the Coastal Range and, to a lesser extent, in the Central Valley and along the lower Andean front. The deposits are caliches in which saline minerals occur as a cement or as impregnations in unconsolidated regolith and fractured bedrock, and as high-purity veins in the cemented regolith and bedrock of all types. The zone of abundant saline minerals in which the host rock is firmly cemented generally extends to depths of only a few meters, but at a few places nitrate ores are found at depths of as much as 12 m. The layer of nitrate ore is highly irregular in grade and thickness. Typical nitrate caliche being exploited in the 1970's contains 7-12 percent NaNO_3 (including small amounts of KNO_3) and is on the order of 1-3 m thick. During the 19th century the caliches that were exploited generally had an average grade of 15 percent or more NaNO_3 ; and some, particularly during the earliest days of mining, averaged 50 percent or more NaNO_3 .

The role of natural nitrates as fertilizers is distinctly limited in a world of mechanized agriculture, because resources are small in terms of present-day fertilizer needs. For example, reserves of NaNO_3 in commercial-grade Chilean nitrate ore (>7 percent NaNO_3) are estimated to be about 200,000,000 metric tons, which is equivalent to 33 million tons of contained nitrogen and is less than world annual consumption during the early 1970's. Probable resources of lower grade caliche (1-7 percent NaNO_3) are several times as great as those of the currently commercial-grade ore, but they are still equivalent to only 2 or 3 years of current world consumption of fixed nitrogen.

A GEOCHEMICAL SUCCESS STORY IN NORTHEAST THAILAND

By Robert J. Hite

Thick beds of rock salt have been penetrated by numerous water wells in the Khorat Plateau of northeastern Thailand and central Laos. These deposits of Cretaceous age occur in the Maha

Sarakam Formation of the Mesozoic Khorat Group.

The salt-bearing Maha Sarakam Formation extends over 21,000 km² in the Sakon Nakhon basin in the northern half of the plateau. An additional 36,000 km² occurs to the south in the Khorat basin. The maximum thickness of the halite facies is unknown but may exceed 1,000 m. In the Sakon Nakhon basin, three salt beds are present. The lowermost bed is 340 m thick at Vientiane and is probably the thickest salt bed in the world.

Preliminary studies of trace bromine and potassium in halite cores from the western edge of the Khorat basin indicated that the thick basal halite bed in Maha Sarakam Formation was a very favorable target for potash exploration.

Following the recommendations based on the bromine and potassium geochemistry, a core hole was drilled at Udon Thani in the Sakon Nakhon basin. This hole penetrated a carnallite deposit at 89 m, which continued to the depth of 130 m. Subsequent drilling has shown this deposit to extend over about 1,800 km² in Thailand. The extension of the potash deposit into Laos has been verified by a core hole recently completed on the Vientiane plain. This hole penetrated a high-grade deposit of sylvite.

Although part of the Sakon Nakhon basin is still unexplored and little drilling has been done in the large Khorat basin, the preliminary results suggest that the Khorat Plateau hosts one of the largest, if not the largest, potash deposit in the world.

PHOSPHATE AND EVAPORITES—A DIRECT RELATIONSHIP?

By Robert J. Hite

Many sedimentary sequences in the world show lateral gradation of phosphorite, chert, carbonate, and evaporite facies. Two classic examples are the Permian Phosphoria Formation and the Jurassic Fernie Group and equivalent rocks of the northern Rocky Mountains, U.S.A. and Canada.

Current theories on the origin of phosphorite facies require no direct relationship with evaporites. This paper proposes that apatite, chert, and dolomite are precipitated by the mixing of warm brines from evaporite basins with cold ocean water. This mixing takes place in and at the mouths of marine accessways to Mediterranean-

type evaporite basins, where high-density brines reflux back to the ocean. The mechanism provides conditions favoring the accumulation of prodigious amounts of organic matter—a common feature of phosphorite facies. Reactions in the basin between the evaporite brine and detrital silicate minerals may mobilize Si, F, Cr, Ni, V, Fe, rare earths, and other elements that frequently occur in anomalously large amounts in the phosphorite facies. Phosphorus, which other theories assume is supplied by the ocean, may be supplied by reactions between brine and detrital apatite from igneous or sedimentary sources. The proposed mechanism may also be responsible for the formation of some sedimentary deposits of barite and iron ore.

POTASH RESOURCES AND ECONOMICS

By C. L. Jones

World production of potash (K_2O) now exceeds 20 million metric tons per year. Slightly more than 96 percent of the total originates in the industrial nations of Europe and North America; the remainder comes mostly from the Middle East, with smaller amounts from Australia, Asia, and South America. Among the industrial nations, four countries—Canada, West Germany, East Germany, and the U.S.S.R.—control 72 percent of the world production capacity and 96 percent of the reserves. The United States produces about one-tenth of the world supply, has less than one-half of 1 percent of the reserves, and imports over one-half of its annual supply.

National and world sources of potash are evaporite and brine deposits. These sources provide known reserves of potash in excess of 120 billion metric tons, and they are sufficient to fulfill world requirements for a few thousand years. Tonnage of reserves obviously is not a problem, but other factors are of immediate concern. The concentration of production facilities and reserves in a few countries favors the development of an international cartel and gives rise to governmental control over the production, distribution, and pricing of potash. All too recently, governmental action in Canada disrupted world trade by glutting the market; this action resulted in the premature closure of potash mines in the United States, a reduction in domestic output, and a loss of potash reserves.

The outlook for the United States is bleak. There will be further reductions in potash supplies from existing domestic sources, a steadily rising demand for potash, and a large increase in imports. This projection suggests that the United States must weigh the alternatives of paying an inflated price for potash on the world market or developing new domestic sources of potash. The latter may be less expensive.

NATURE OF THE PHOSPHORIA SEA AND THE RELATION OF UPWELLING TO RICH PHOSPHATE DEPOSITS

By Keith B. Ketner

Upper Middle Pennsylvanian to Upper Permian conglomeratic, sandy, and silty rocks cover part of southern California, most of Nevada, and much of Idaho. Their distribution, facies trends, and current vectors indicate that detrital components were shed mainly from a tectonic belt of highlands that extended generally northward through southern California, central Nevada, and western Idaho. Their enormous volume suggests that the provenance terrain was of major proportions. Sediments shed eastward from this belt were deposited in the shallow epicontinental Phosphoria sea, where they mingled with limestone, dolomite, evaporites, spicule chert, and phosphorite; but those shed westward were deposited in deeper water off the edge of the continent as debris flows and turbidites and they mingled with coarse volcanic sediments, tuffs, lava flows, and radiolarian cherts. The volcanic sediments, tuffs, and lavas emanated from an archipelago that lay parallel to, and a short distance west of, the tectonic belt. The tectonic highlands formed a barrier between the ocean to the west and the epicontinental Phosphoria sea to the east, with profound effects on sedimentation in the latter. Obviously the highland belt supplied an enormous volume of detrital material; but, beyond that, it probably indirectly affected sedimentation by restricting circulation of both water and air. It served as a barrier between the Phosphoria sea and the ocean. Without such a barrier the formation of evaporite beds would have been impossible and the formation of extensive dolomite beds unlikely. The exact conditions under which phosphorite was deposited are

poorly understood, but the abundance of phosphorite east of the highland belt and its scarcity west of it suggest that restriction of circulation was important. The effect of the Humboldt belt on air circulation can only be guessed, because its topographic relief is unknown and atmospheric circulation patterns before uplift of the highland belt are unknown. To the extent that the highland belt was a mountain range, it must have had the effect of increasing aridity over the Phosphoria sea, for it would have formed a barrier to moist oceanic air and would have promoted evaporation and hypersalinity.

The currently popular concept of Kazakov (1937), which relates rich phosphate deposits directly to upwelling oceanic waters, should be regarded only as a working hypothesis, not as a proven theory. New information and new concepts on which to base additional working hypotheses are needed, because too much reliance on a single concept in exploration could result in failure to locate important deposits. The need for new ideas can be illustrated by a consideration of the exact spatial relation of known commercial phosphate deposits of the Phosphoria sea to possible sites of upwelling.

Although it is hardly conceivable that upwelling could have taken place within the shallow, restricted Phosphoria sea, it is theoretically quite possible that deep-seated oceanic waters welled up along the western edge of the continent, west of the highland belt, in Permian time. However, phosphate beds of commercial grade are not known to have been deposited outside the Phosphoria sea, where upwelling may have taken place, nor in the western part of the sea close to the upwelling waters; but, rather, they were deposited near the center of the widest part of the sea, hundreds of kilometers from the nearest possible site of upwelling oceanic waters. If exploration for phosphate in the early days had been based on an assumed close genetic connection with upwelling oceanic waters, the commercial phosphate deposits of southeastern Idaho would not have been discovered.

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ENERGY REQUIREMENTS OF THE AGRICULTURE INDUSTRY

By Richard F. Meyer

The United States appears to possess large resources of potassium in the form of potash, phosphorus in phosphate rocks, nitrogen in atmospheric nitrogen, and sulfur in many forms. These are the essential ingredients for fertilizer.

The potash is crushed and separated from other salts by flotation or fractional crystallization and may then be applied directly. The major energy required, in addition to that needed for mining and milling, is heat for drying. About 94 percent of potassium goes for agricultural chemicals.

Phosphate rock is decomposed with sulfuric acid and applied as fertilizer in several forms. Eighty-four percent of phosphorus demand is for fertilizer and 10 percent for animal feed.

About half of all sulfur mined is used in fertilizer manufacture, and 72 percent of elemental sulfur is obtained by the Frasch process, which depends entirely upon natural gas for heating the processing water.

Nitrogen for agricultural purposes is supplied in the form of ammonia, which is either applied directly or used to make other fertilizer materials. The ammonia is synthesized from nitrogen and natural gas.

At least 16 billion m³ of natural gas per year are required for the fertilizer industry, of which about 14 billion are needed to synthesize ammonia. Because of natural-gas-supply curtailments, there will be a curtailment this year (1975) of 400,000 to 500,000 metric tons of ammonia.

As a whole, the agricultural industry requires 13 percent of the total U.S. input of 37 quadrillion kcal/kg of energy. This energy is needed for farm production and family living, food processing, marketing and distribution, and input manufacture, including fertilizer and pesticides.

If the energy crisis is, in fact, more appropriately an investment capital crisis, then any potential agricultural shortfalls due to the energy crisis must also be resolved in terms of investment capital.

UPWELLING MODEL AND ITS APPLICATIONS

By R. P. Sheldon

The history of exploration for a mineral resource generally begins with an empirical-technique

phase and, after geologic knowledge and theory have been developed to explain the distribution of the deposits, ends with a deductive-technique phase. Phosphate exploration was empirical until about 1950. After 1950, when the upwelling theory of the origin of phosphate was developed, this theory was instrumental in the discovery of deposits in Baja California, Sechura desert of Peru, Huancayo district of Peru, Australia, India, Angola, and extensions of phosphogenic provinces in North Africa and the Middle East. The upwelling model was described by McKelvey (1963, 1967), McKelvey and others (1953), and Sheldon (1963), and the Phosphoria Formation example developed by McKee and others (1967). This deductive exploration technique uses, more or less sequentially, the following geologic theories and tools as guides: regional tectonics, plate tectonics, reconnaissance-level stratigraphic sections, chert-black shale-phosphorite association, and uranium association. Is the theory still useful? Yes, but the theory is becoming less useful as the deposits that can be found with it are found. Some important deposits do not fit this model well, if at all; these include the Florida-North Carolina Tertiary deposits and the Rajasthan, India, Precambrian deposits. These deposits should be studied intensively if we are to develop new theory and new deductive exploration techniques.

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SOIL AMENDMENT MATERIALS

DISTRIBUTION OF VOLCANIC ROCKS POTENTIALLY USEFUL AS SOIL AMENDMENTS

By Alfred L. Bush

Glassy volcanic rocks appear to be most suitable for use in upgrading soils because they break down easily in the weathering environment. They release such elements as K, P, and Fe to soil solutions at low-energy levels, because the elements are not tied up in crystal lattices. A variety of glassy rocks are available as soil amendments, ranging widely in composition (basaltic, andesitic, rhyolitic), in texture (ash, pumice, obsidian, perlite, scoria), and in form (air-fall blankets, reworked bedded deposits, flows, domes, cinder cones). Although volumes and tonnages are very large, distribution is spotty.

Because glasses do not persist for geologically long periods, they are mostly Miocene in age or younger. They occur in the western parts of North and South America, through Central America, in the islands of the Pacific Ocean, along the eastern borderlands of Asia and Southeast Asia, through the Indonesian Archipelago, and in parts of eastern Australia and New Zealand. Another major zone extends through the Mediterranean area, the Balkans, and Asia Minor into India; and a third, in a very generalized way, follows the Rift Valleys of Africa and extends into the western Arabian Peninsula.

Utilization of these rocks depends on a multitude of factors, including (1) rates of release of elements from glass in a variety of climatic and agricultural environments, (2) specific element deficiencies in specific environments, (3) needed tonnages and costs of distribution and application of the natural materials, and (4) relative economics and efficiencies of the use of alternative natural and manufactured materials. We have far more questions than answers.

PEAT AS A SOIL AMENDMENT

By Cornelia C. Cameron

Peat forms mainly from dead plant remains and occurs in bogs, swamplands, or marshes. It has an ash content not exceeding 25 percent by dry weight according to the ASTM standard. Ash is defined as the solid material that remains after the peat is

heated to 550°C. The organic content and the ability of peat to hold water in its fibers make it valuable as a soil amendment. In addition to its moisture-storing ability, peat produces a humic acid, through slow decay, that moderates the uptake of mineral fertilizer by plants. Peat, therefore, helps prevent plants from being "burned" by the mineral fertilizers and promotes increased crop yield.

Peat bogs underlie 150 million ha of the world's land surface. They contain deposits ranging from high-quality peat that is excellent for soil amendments to organic soils that have little or no soil amendment capacity. Ninety-three percent of the bogs are located chiefly in latitudes north of the United States. Five percent are in the United States, and the remaining 2 percent, at the same latitudes and south.

The United States does not produce enough peat to meet national consumption; yet, undeveloped deposits of peat, excellent for soil amendment use, are believed to lie in the Eastern United States, in the Rocky Mountains, and in States bordering the Great Lakes and the Pacific Ocean. Peat producers are beginning to mine deposits in central Florida drained during phosphate mining operations. Here, phosphate fertilizer is mixed with peat and sold to citrus growers.

Undoubtedly, peat resource potentials exist in other countries and could benefit agriculture. For example, Uganda has deposits of peat in areas of clay soils, India has deposits of peat in its uplands, and the Latin American countries have deposits of mangrove peat in the tropics as well as reed-sedge peat in Argentina.

Peat prospecting techniques are being studied in this country to enable peat producers to expand the growing need for peat; production in 1973 was 10 percent above that of 1972. As we become more self-sufficient in using peat in conjunction with fertilizers, our example may be followed by other countries in which peat exists and food is needed.

LIMESTONE AND DOLOMITE IN AGRICULTURE

By Harold A. Hubbard
and George E. Erickson

Liming of agricultural soils is common practice in regions of acid soils in developed nations. Liming has two effects: (1) It acts as a fertilizer furnishing calcium and magnesium, which are essential

to plant growth; and (2) it acts as an amendment that causes an increase in soil pH (hydrogen ion concentration). The pulverized stone may also improve the physical structure of clayey soils, thereby increasing permeability.

Acid soils predominate in areas of moderate to relatively high rainfall and are particularly prevalent in the humid tropics. Many acid soils in temperate or tropical areas respond dramatically to liming by showing significant increases in crop yields.

Limestone and dolomite promote plant growth because an increase in pH makes more cations available for exchange in soil solutions. Plants can use metallic cations, whereas non-ionized metals adsorbed on soil particles or in chemical compounds cannot be used. As the hydrogen ion concentration of soil or soil solution decreases, metallic elements ionize more readily and the concentration of metallic ions in the soil solution increases.

As the carbonates dissociate, metallic ions are exchanged with hydrogen adsorbed in soil solution and on clay particles. When limestone is added to the soil, new equilibria are established; calcium ions from the limestone replace hydrogen at exchange sites on clay particles and the hydrogen forms water by combining with oxygen from the carbonate radical.

Liming in general is beneficial to plant growth, but its effects vary with different plants. Most crops grow best in slightly to moderately acid soil. A few crops grow well only in relatively strongly acid soils, and a few others grow well only in nearly neutral soils.

In countries where farmers have total cash incomes of tens to hundreds of dollars a year, many farmers cannot pay for limestone, fertilizers, and other soil additives. In these countries farmers may use lime or fertilizer only if it is paid for with government or foundation aid. However, the value of increased crop production due to liming will generally far exceed the cost of the lime and its application, and could contribute to many national economies by materially reducing food imports.

SOIL AMENDMENTS AND PHYSICAL PROPERTIES OF SOILS

By R. C. Severson

The use of soil amendments to improve physical properties of soils must be put into perspective in

terms of plant growth factors. Moisture, nutrients, heat, light, and a medium (soil) are all necessary for plant growth. The improvement of physical properties of soils is aimed at increasing the efficiency, or ease, with which the plant is able to assimilate the other factors. If any of the factors are limiting, it will serve no useful purpose to alter factors that are not limiting. Therefore, physical properties of soils should be altered only if they are suspected of being limiting to plant growth.

Within the soil, physical, chemical, biological, and microbiological processes are integrated so that a process cannot be singled out and treated alone. The physical properties and processes of soils can be treated as a singular entity while the chemical, biological, and microbiological changes which are related to and result from changing physical soil properties are ignored.

Certain features of the soil landscape are more amenable to change than others. Soil features such as structure, moisture, aeration, and temperature are subject to change by amendment with some extraneous material, but "permanent" soil features such as texture, slope, ground water, flooding, and climate are not readily changed by the simple incorporation of some extraneous material into the soil. We should concentrate our first efforts on those soil features that are amenable.

Soil porosity and soil structural stability (aggregation) are the targets of soil physical amendments. These two properties effectively determine the magnitudes of water infiltration, water retention, water runoff, soil dispersion, soil-surface crusting, soil aeration, and soil temperature. Soil porosity and aggregation are responsible for the quality of physical soil environment available for plant growth.

The properties of materials that account for their usefulness as physical soil amendments are particle size, surface area, and exchange capacity.

Mechanized agriculture results in soil properties being modified by powerful machines. The required energy is as yet more economical than the use of soil amendments to maintain adequate physical soil properties for plant growth. As energy becomes more expensive, as expanding populations demand more production from a finite resource (the soil), and as lands considered marginal for agriculture are brought into production, the potential of amendments for improving or maintaining soil physical properties will be recognized.

The task of determining the potential of various amendment materials is largely one for agricultural scientists. Crop response, in terms of yield, to various amendment materials is determined by the specific combinations of plant growth factors at the site. The response can only be quantified by empirical methods, as has been the usual approach in soil fertility studies. The main role of the scientist in the U.S. Geological Survey is perhaps locating and characterizing the sources of potential amendment materials and characterizing the specific properties of the materials themselves. It follows that a cooperative effort would lead to the most efficient utilization of available expertise.

RECOMMENDED TERMINOLOGY

The terms, additive, admixture, amendment, conditioner, fertilizer, and stabilizer have been variously used to describe types of soil modification. The absence of a generally accepted terminology for describing specific soil modification processes aimed at specific uses leads to confusion.

The dictionary presents the following meanings for each of the words:

Additive—to be added, of the nature of an addition, characterized by addition.

Admixture—anything added, an alien element or ingredient.

Amendment—act of amending, correction, improvement.

Condition(er)—a restrictive, limiting, or modifying circumstance.

Fertilizer—any material used to enrich the soil for crops, especially a commercial or chemical manure.

Stabilizer—any compound which, when included with a material, decreases the ability of the material to decompose spontaneously.

Inasmuch as additive, admixture, and stabilizer are generally used in describing the modification of soil properties for engineering purposes, I propose that these terms not be used in referring to the modification of soil properties for agricultural purposes. Conditioner and amendment have the same general connotation, but since the label conditioner has been employed quite extensively in the agronomic literature for synthetic materials used in the modification of soil properties for agronomic purposes, I propose that amendment be employed to describe materials of geologic origin used in agronomic aspects of soil modification. The remaining terms should be employed in agreement with their intended function and prefixed with descriptive terms to further describe their mode of action. For example, if limestone is incor-

porated into the soil to specifically supply calcium for plant growth, it should be referred to as an inorganic fertilizer. If limestone is incorporated into the soil with the intent of changing the soil pH, it should be referred to as a chemical amendment.

I have limited the list of employable terms to two—fertilizer and amendment. The rationale is to avoid confusion in use and interpretation, and to simplify the terminology and yet retain integrity. This can be obtained by using the terms with modifiers to make their intended meanings clear.

POTENTIAL ROLE OF NATURAL ZEOLITES IN AGRICULTURE AND ANIMAL HUSBANDRY

By Richard A. Sheppard

Zeolites, crystalline hydrated aluminosilicate minerals of the alkali and alkaline-earth elements, are important rock-forming constituents in sedimentary rocks and are potentially valuable industrial minerals. Although more than 30 species of zeolites occur in nature, only about six occur abundantly in sedimentary deposits. These are analcime, chabazite, clinoptilolite, erionite, mordenite, and phillipsite. These zeolites are very finely crystalline ($<1\text{--}60\ \mu\text{m}$) and are especially common and abundant in Cenozoic tuffs. Zeolites in sedimentary deposits have been recognized in about 40 countries throughout the world, but only in Japan are deposits being used in food production. The properties of zeolites that make them useful for agriculture as well as industry include cation exchange, adsorption, and reversible dehydration.

The Japanese use zeolitic tuffs as (1) soil amendments that neutralize acid soils and release small amounts of exchangeable potassium, (2) zeolite-chemical fertilizer mixes that improve the soil's retention of nitrogen and result in more complete utilization of the nitrogen by plants, (3) low-grade fertilizer after application to cattle feedlots, and (4) carriers for insecticides and herbicides. Other potential agricultural uses are as low-grade fertilizer after use in tertiary sewage treatment plants and as material added to Sr^{90} -contaminated soils to reduce the strontium uptake by plants.

Besides the application to cattle feedlots, the Japanese use crushed clinoptilolite-rich tuff to deodorize and dry the excrement of pigs and chick-

ens. The spent zeolite-excrement mixture is then used for fertilizer. Another use in animal husbandry is the addition of 5 percent clinoptilolite to the feed of pigs and chickens. Test animals experienced faster growth than control animals, and less feed was required. Severe cases of scours (diarrhea) in pigs were relieved when the afflicted animals were placed on a diet containing 15 percent clinoptilolite.

Three areas warrant further attention: (1) We need to set up communications between geologists and food industry personnel—if only to let them know that a voluminous natural resource exists that has great potential but has been mostly ignored; (2) accelerated experimental work is needed, chiefly by those in agronomy and animal husbandry, on the utilization of natural zeolites; and (3) we should prepare an inventory of worldwide zeolite resources with special emphasis on the countries of Southeast Asia and Central and South America.

HUMATE AS A SOIL ADDITIVE

By Vernon E. Swanson

Humate is a naturally occurring, dark-brown to black, solid organic substance that is formed during the oxidation and decomposition of plant material, is soluble in slightly alkaline water, and can be transported in water in its soluble or colloidal forms, which are the humic acids or fulvic acids common in the tea-colored streams of swamps and peat bogs. When precipitated either by encountering acid water ($\text{pH} < 3$) or seawater, or by adsorbing excess metal ions, humate is a structureless gel that solidifies to a brittle, glistening coal-like material indistinguishable from vitrain in appearance. Its ash-free composition is generally about 60 percent carbon, 4 percent hydrogen, 35 percent oxygen, and 1 percent nitrogen. Humate having the same chemical characteristics is similarly derived from oxidizing peat and lignite.

The following properties of humate make it useful in the fertilizer business:

1. Its solubility characteristics in natural waters.
2. Its ability to adsorb plant-nutrient metals to as much as 20 percent dry weight, and to release these metals in a plant-available form.
3. Its organic composition, which contributes to the humus content of the soil.
4. Its abundant resources, which can be cheaply processed for market distribution.

The major, but still limited, agrobiologic use of humate has been as a nutrient-metal (for example, Fe, Cu, Mn, and Zn) soil additive, either applied as a granulated solid or added to irrigation water, especially for horticultural and hydroponic use.

Two major sources of humate are (1) the humate-impregnated sands irregularly distributed along parts of an 80-km-wide coastal belt from Pamlico Sound, N. C., on the Atlantic Ocean, to Mobile Bay, Ala., on the Gulf of Mexico; and (2) the irregularly distributed leonardite deposits associated with, and parts of, the lignite and sub-bituminous coal of the Northern Great Plains States. No reliable estimates of humate resources exist, but the humate that can be readily obtained from each of the above sources is reckoned in the hundreds of millions of metric tons. Considering that the yearly production of humate is 50,000 metric tons or less, it would be relatively simple to delineate recoverable reserves that would last many hundreds of years. For example, the Trail Ridge heavy minerals mine in northeast Florida alone has a "byproduct stockpile" of about 10 million metric tons of humate, which is more than a 200-year supply of humate based on present demand.

Any great increase in the use of humate in agriculture will depend on (1) the refinement of knowledge of micronutrient deficiencies in specific food plants and animals grown in different areas, and (2) an improvement in technology to custom-process different humate additives that will meliorate these deficiencies and result in optimum growth characteristics and nutritional value of the product.

VOLCANIC ASH AND RELATED MATERIALS AS SOIL AMENDMENTS

By Ray E. Wilcox

During the present century the suggestion has been made repeatedly that pyroclastic materials should be mixed into crop soils to provide paced release of plant nutrients, such as K, P, Ca, and Fe, and to improve physical properties of the soils. One basis for the suggestion is the apparent fertility and productivity of certain young soils developed on terrains covered by volcanic ash that is chiefly of basic and intermediate composition.

Interesting and appealing as this proposition seems, few definitive agronomic tests have been reported (in striking contrast to the many investi-

gations of natural volcanic-ash soils and their own special problems).

The geologist can indicate the varieties of young pyroclastic materials and the accessible deposits. A careful assessment of the current knowledge of natural volcanic-ash soils may provide an idea of the benefits to be expected from addition of such material to normal soils. The critical answers, however, await results of controlled field trials by agronomists and soil scientists.

WEATHERING OF ROCKS, SOILS, TRACE ELEMENTS, AND PLANT NUTRITION

THE IMPORTANCE OF ELEMENTAL INTERRELATIONSHIPS IN BIOLOGICAL SYSTEMS

By Helen Cannon

Widespread areas of crop deficiency exist in the United States and in many countries of the world. Many deficiencies in plants are induced by the addition of fertilizers, which changes the availability of other elements. Various crop species have different requirements and tolerances for available elements, and so absolute levels cannot be determined for the growth of all plants. Animals (including man) are also strongly affected by imbalances in available nutrients. Certain interrelationships such as Ca-Zn, Cu-Mo, and Na-Li-K have been linked with specific diseases.

To improve crop quality, the agronomic situation must be thoroughly understood and the effects of additives on the availability of other elements must be anticipated. Crop plants that are particularly tolerant of abnormal soils or particularly efficient at absorbing scarce nutrients may be substituted for the plants commonly grown.

SOIL CHEMICAL PROPERTIES AND PLANT NUTRIENT AVAILABILITY

By T. T. Chao

In order to evaluate the effectiveness of a fertilizer in soil, two factors related to plant nutrient availability should be considered—the intensity factor and the capacity factor. The intensity factor represents the concentration of a given nutrient in the soil solution, and the capacity factor represents the ability of the soil to maintain that intensity in

the soil solution, or the rate at which a nutrient concentration can be reestablished after uptake by plants. Whether an applied fertilizer will be satisfactory is greatly affected by chemical and mineralogical properties of the soil.

Because the soil solution is not a simple aqueous solution, there is a constant reaction between the nutrient element supplied by a fertilizer and the solid components of a soil. One of these reactions, important from the standpoint of plant nutrient availability, is fixation of a nutrient element by soil, whereby availability of the nutrient is drastically reduced. Moderate retention, however, may be beneficial to plant growth, because it lessens the risk of leaching loss of the nutrient element.

Fixation or retention by soils of phosphate and sulfate, and of several micronutrient elements such as cobalt, molybdenum, and boron may be influenced by numerous factors. Among these are the content of secondary iron, manganese, and aluminum oxides, and the degree of crystallinity of the oxides. Amorphous oxides usually can fix large amounts of the above nutrient elements in forms not readily usable by the plant. In extreme cases, considerable amounts of a nutrient element may be rendered unavailable to the plant.

Certain soils, especially those containing vermiculite and degraded illite clay minerals, have the ability to fix potassium and ammonium added as fertilizers in much less available forms. An explanation for the striking similarity between the capacities of these soils to fix potassium and ammonium can be found in the "lattice cavity" theory. According to this theory, cation fixation is related to the size of the cation as well as to the mineralogy of the fixing materials. Cations that fit snugly into openings of the exposed surface between the layers of 2:1 lattice-type minerals will be fixed very tightly as they approach the negative electric charges of the crystal lattice.

PROBLEMS OF LATERITIC SOILS

By W. R. Griffitts

Laterites, in a strict sense, are soils that are hard enough to be used as building material or become hard upon exposure to weather. Lateritic soil is one that contains laterite. For purposes of discussion, I include saprolite as a lateritic soil.

Laterite and lateritic soils result from nearly complete leaching of alkalis, alkaline earths, and combined silica. Aluminum, iron, and, in some

places, manganese, phosphate, or other elements of the R_2O_3 group are concentrated.

Old laterites contain kaolinite, gibbsite, and limonite as the dominant minerals. Those no older than Pliocene contain more amorphous silica and alumina, halloysite, and allophane, which may be more effective in making phosphate unavailable to plants. The relation is not entirely clear inasmuch as soils in western Africa containing allophane and much organic matter are said to have a longer lasting fertility than allophane-free soils.

In forest and savannah areas, the plants' roots gather some of the trace amounts of nutrients from large volumes of lateritic soil. These accumulate in a thin layer near the surface as plant debris decays. Potassium, calcium, phosphate, sulfur, zinc, and, to some extent, magnesium show such surficial concentrations. The trees in one hectare of a 40-year-old forest in Guinea were estimated to contain 127 kg of phosphorus, 829 kg of potassium, 2,556 kg of calcium, and 350.5 kg of magnesium. The plants in the savannahs contained one-third to one-ninth of these amounts. Nitrogen and sulfur were not included in the estimates because they are largely lost when the plant material burns, a common preliminary to cultivating the land. Other studies suggest that these elements probably constituted a few hundred kilograms of the plant material on 1 ha of land. This surficial concentration of plant nutrients is the basis of "slash and burn" agriculture. In Indonesia and the mountains of Burma, one crop can be raised every 5 to 10 years. In subtropical China this kind of agriculture has been carried on for several thousand years with no reported ill effects. Improper technique or attempts to raise unsuitable plants can severely damage the soil.

Lateritic soils are widespread in Southeastern United States, show the usual low contents of several important plant nutrients, and, as a result, are less intensively cultivated than other soils.

MAJOR NUTRITIONAL ELEMENTS IN SOILS AND PLANTS—A BALANCE SHEET

By Hansford T. Shacklette

Food produced on agricultural lands exploits a nonrenewable resource—the natural supply of major and minor nutritive elements in the soil. Not only the elements contained in the food that is removed from the land, but also the element losses associated with agricultural practices, such as

those caused by erosion, leaching, and volatilization, must be replaced if acceptable crop yields are to be maintained. In agrarian societies the losses from soils can be greatly reduced by returning plant, animal, and human wastes to the soil from which they came through labor-intensive practices, if a relatively low yield of produce is acceptable. This system of management does not result in an increase in essential elements in the soil—naturally poor soils will gradually become poorer—and crop yields will reflect the element deficiencies. The cost of food then becomes a major item in the economy of the society. In societies having a well-developed industrial base, on the other hand, agricultural soils are brought to the level of maximum crop yields by utilizing additional sources, largely geologic in origin, for supplying the essential plant nutrients, particularly phosphorus, potassium, and nitrogen. This system of management results in energy-intensive practices, low labor requirements, and high crop yields, which make food relatively inexpensive; it also permits the accumulation of a food surplus for export.

The movement of phosphorus through the human food chain can be used as an example of the losses in essential plant elements that must be corrected by application of "commercial" or "chemical" fertilizers. Much of the phosphorus contained in our foods eventually enters city sewers. The total municipal sewage solids produced per year in the United States is estimated to be 45 million metric tons. This amount of sewage, on the basis of analyses of metropolitan Chicago sewage, contains 1.7 million metric tons of phosphorus, and only a small percentage of this total is returned to the farm lands where it originated and where it can reenter the human food chain. Much of the United States diet consists of meat of animals that were fed grains in feedlots. In 1970, 24,970,000 head of cattle were in U.S. feedlots, each animal producing an average of about 27 kg of manure per day, resulting in a total of about 250 billion kg of manure per year. On the basis of an "average" analysis of this manure, 5 billion kg of phosphorus are contained in this annual manure output. Much of this phosphorus is never effectively recycled in food production. There is another less commonly considered sink for the elements contained in our foods—the human body. Ash of the human body contains about 24 percent phosphorus, and the ash constitutes about 5 percent of live weight. Assum-

ing that the "average" human weighs 45 kg and that the present U.S. population is 219 million, there are 113 million kg of phosphorus in the bodies of this population. Regardless of whether these figures are accurate, two important aspects stand out: (1) This phosphorus was principally derived from the available phosphorus in soils, which constitutes about 5 percent or less of the total soil phosphorus; and (2) most of this phosphorus will never again enter the food-production chain.

The elements in foods that are exported represent a total loss to the agricultural soils of a country. For example, one railroad carload of wheat weighs about 2.7 metric tons, and this amount of wheat contains about 11 kg of phosphorus. An "average" hectare of U.S. soils contains about 146 kg total phosphorus in the plow zone, but only a small amount (about 45 kg per ha) exists in a form available to plants. At a yield rate of 3.4 metric tons per hectare, the crop of wheat removes about 13.4 kg of phosphorus from a hectare of soil. Erosion losses can be estimated at 11.2 kg per ha. These two losses, 24.6 kg, would exhaust the available phosphorus in a hectare of soil in 2 years, in the same time that a carload of wheat was being produced on the hectare.

The losses in potassium using the same cropping procedures are equal to, or greater than, those of phosphorus. Certain management practices can reduce these losses; but, in the long run, our exportation of foodstuffs exploits a nonrenewable resource just as surely as does the exportation of petroleum or metals. For example, Hawaii exports 2,000,000 kg of potassium annually in its pineapple crop alone. The net losses in nutrient elements by another country, Ecuador, are exemplified by its exportation of 4,600,000 kg of potassium annually in its banana crop, while importing only half this amount of potassium in fertilizers. The balance sheet for two other major nutrient elements, nitrogen and sulfur, generally follows the trend in losses of phosphorus and potassium, except that certain amounts of the two former elements are added to the soil by natural processes.

These examples illustrate the general trend in soil depletion by food production that must be corrected by applications of fertilizers. Even the best systems of returning unused crop residues and animal wastes to the soil, sometimes called "organic farming," will only reduce but not eliminate the loss; they also result in yields unacceptably low in relation to the world demand for food. Moreover,

the economics of technologically advanced food production do not at present permit advantageous use of organic fertilizers. To produce maximum crop yields, the cost of obtaining and applying sufficient organic material (which contains only low percentages of the major nutrient elements) contrasted to the cost of using high-test commercial fertilizers cannot be justified economically. The present trend is to apply more of the plant nutrient elements as "chemical" fertilizers per year than are removed from the soil in foodstuffs in order to allow for volatilization, chemical fixation, leaching, erosion, and other losses. Commercial fertilizers obtained directly or indirectly from geologic sources form the basis of U.S. agricultural systems; they permit food to be produced in excess of national needs so that an exportable surplus remains.

COMPOSITION AS A MEASURE OF SOIL QUALITY

By Ronald R. Tidball

An extensive study of soil composition throughout the State of Missouri provides basic data that may be applied to the solution of various problems. Examples are presented to illustrate the usefulness of this type of study.

Do these soils have a basic chemical signature? This fundamental question was investigated by factor analysis using the total composition of soils as expressed by 32 elements (Tidball, 1973). Approximately 95 percent of the variance in the samples could be accounted for by only 16 elements. These are aluminum, barium, carbon, calcium, gallium, iron, lithium, magnesium, potassium, scandium, silicon, sodium, strontium, titanium, vanadium, and zirconium. The samples may be best described by a four-factor model in which the theoretical end-members are best related to the predominating parent materials.

Human mortality data compiled according to cause of death within Missouri counties were compared with the soil composition within corresponding counties using multiple regression procedures (Tidball and Sauer, 1975). This was a test of the hypothesis that the mortality rate of the human population is proportional to the quality (as measured by element concentration) of the soils in the locality of their longtime residence. Little significant association was found, so the hypothesis cannot be accepted. This finding suggests that either

the hypothesis is much too simplistic or we failed to measure the most appropriate properties of the soil.

Birth defects among swine were also compiled according to type of defect by Missouri counties and were compared to the corresponding soil composition data (Selby and Tidball, in press). The hypothesis that was tested was that the frequency of occurrence of a birth defect was associated with the composition of the soils within the corresponding locality. The hypothesis was better supported here than with human populations, perhaps because the swine are in more intimate contact with the soil. Nearly 50 percent of the variance in selected birth defects was related to phosphorus concentration in the soil.

The quality of soil (or land) for general agricultural use has been routinely judged during the soil mapping program of the Soil Conservation Service using criteria such as soil texture, drainage, profile depth, rockiness, and slope. Chemical composition could not be included as a criterion because the data were unavailable. The U.S. Geological Survey has been developing methods by which such data could be obtained. Maximum yields of agricultural products (plants and animals) are achieved in those areas where the conditions of temperature, water, and soil quality are simultaneously optimum. Land-use priorities could be designed according to land-classification units that recognize this unique combination of factors. Those areas that have great potential for food production should not be permanently assigned to support the physical structures of man, such as buildings, highways, parking lots, and reservoirs.

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WEATHERING, AND THE PARENT MATERIALS OF SOILS

By R. W. White

The parent material of a soil is defined as that material from which the A and B horizons of the soil were derived—which may (or may not) be the same as that in the horizon underlying B. It is weathered rock or other loosely consolidated material. The influence of the parent material on properties of a soil decreases with time and progressive soil development, but it is never eliminated. Soil boundaries, clay mineralogy and content, nutrient content, tilth, depth, grain-size distribution, permeability, and other properties of soils are influenced or controlled by the parent material. These properties have an important effect on the agricultural productivity of the soil.

Geological studies can and should be useful to students of soil genesis; but, in practice, conventional geologic mapping, as it presently is conducted by the U.S. Geological Survey, is of minimal value to pedologists and soil mappers. The reasons for this are several:

Few agricultural soils are residual, derived directly from bedrock. Thin surficial deposits such as loess are responsible for the productivity of many soils that at first glance appear to be residual. Conventional geologic studies typically ignore such deposits.

Even where soils are truly residual, the rocks and residual parent materials exert their influence through their lithology, such as the clay mineralogy of shales, the plagioclase and biotite contents of volcanic rocks, and the insoluble residue of limestones. Conventional mapping of rock-stratigraphic units does not address such aspects of lithology.

The most important agricultural soils, except for tropical areas, are derived from young unconsolidated materials. These have high sustained natural fertility because they contain large amounts of unweathered silicate minerals throughout the profile, are relatively deep but not excessively leached, generally have good tilth, and are gently sloping to level. Relatively little lithologic mapping of such materials has ever been done by the U.S. Geological Survey, particularly in important agricultural areas.

The following studies, if implemented, could have an influence on pedology and soil science and thereby on food production:

1. Lithologic mapping of surficial materials, determining mineralogy (primarily silicates and clays), grain-size distribution, permeability and its orientation, and total-element chemistry.
2. Preparation of interpretative maps based on the above studies, urban-area studies, or studies of other regions of intensive geologic mapping (Kentucky), showing the parent materials of soils and, by implication, potential agricultural value of soils.

RELATED STUDIES

COMPUTER-BASED DATA SYSTEMS FOR FERTILIZER MATERIALS

By Simon M. Cargill

The study of food and fertilizers requires the collection of large volumes of data. These data can be stored in a computer file while awaiting further analysis. CRIB presently contains several hundred records on phosphates, potash, and nitrates, but these data are being moved to a data handling system that will provide a user with interactive access to the files. The new system is GARNET, which accesses the CRIB file and allows a user to produce graphic displays of the areal distribution of deposits, as well as to update and maintain the data file with new information. In addition, analysis of problems and decisionmaking aids are associated with GARNET as independent modeling programs. Finally, GARNET and CRIB files are an integral part of a teleconferencing system called FORUM, which links together experts through use of the fertilizer-materials data base.

HOW REMOTE SENSING CAN ASSIST IN MAPPING SURFICIAL AND FERTILIZER MATERIALS

By Roger B. Morrison

To aid in detecting conditions at the Earth's surface, remote sensing uses instruments ranging from aerial cameras to side-looking radar to sense the reflected or emitted energy from various parts of the electromagnetic spectrum. Aerial cameras and multispectral scanners, which utilize the visible-light and near-infrared regions, are the operational workhorses—they are the cheapest and

easiest to operate and yield the greatest amount of geologic-terrain data (tables 1–2). These photographic sensing systems, operated from medium- and high-altitude aircraft and satellites, have the following advantages:

1. Superior spatial resolution.
2. Record maximum amount of geologic-terrain information.
3. Metric capability (for planimetric accuracy).
4. Relatively low cost.
5. Photography and processing relatively simple; complicated circuitry and calibration not needed.
6. Multispectral capability (including color and color-IR).
7. Interpreted by conventional techniques.

In contrast, they have these disadvantages:

1. Require daylight and clear weather without clouds.
2. Limited to visible and near-infrared spectrum.
3. Not “real time” (delayed processing).
4. Potential for enhancement less than for digitally recorded imagery.

SLAR (side-looking airborne radar), which operates from aircraft, also produces useful data and has the following advantages:

1. Day and night and virtually all-weather capability (penetrates most cloud cover).
2. Single images cover large areas.
3. Rapidly acquired.
4. Oblique “illumination” aids in recognition of obscure faults, fractures, and outcropping strata, often better than with airphotos.
5. Orientation and angle of “illumination” can be changed at will, in contrast to the orientation of illumination in airphotos.
6. Modern SLAR imagery has good planimetric accuracy.
7. Megaview with moderate resolution suppresses minor surface details (such as vegetation), thus enhancing larger geologic features.
8. Interpretation of imagery is similar to (though different from) conventional photogeologic interpretation.
9. Stereoscopic viewing is possible from overlapping radar imagery.
10. Longer wavelengths penetrate some vegetation and the top few millimeters of soil.

However, it has three limitations:

1. Moderate resolution.
2. High cost.
3. No information from shadowed zones.

Unfortunately, remote sensing offers little promise of finding new deposits of mineral fertilizers in the United States. Surface deposits already are known, and subsurface ones are not amenable to discovery using this technique. There is greater promise of aiding in the discovery of surface deposits of fertilizers in poorly mapped foreign areas and also of aiding the exploration for various mineral soil amendments, such as agricultural limestone, gypsum, volcanic ash and pumice, peat, and sedimentary zeolite soil conditioners, both within the United States and offshore.

Probably the chief way that remote sensing can aid in the production of foodstuffs is through the general and specialized mapping of soils (table 3). Even in the United States, large areas lack adequate soil maps. Specialized soil maps, focusing on such topics as soil depth, nutrient-deficient soils, saline and alkali soils, toxic soils, erosion damage and erosion hazard, and poorly drained soils are needed in order to plan for optimum food production. Multispectral, multiseasonal aerial photography or scanning are the best tools for efficient and rapid production of soil maps, both general ones such as soil associations and soil capability for agriculture, and also specialized ones such as soil limitations and problem soils.

TABLE 1. — *Photographic sensing systems, operated from medium- and high-altitude aircraft and satellites*

| Spectral region | Wavelength | Common applicable imagine sensors |
|---|---------------------------|--|
| Near and middle ultraviolet. ¹ | 0.280–0.393 μm | Photographic film (quartz lenses); scanners with photomultiplier detectors; image-converter tubes. |
| Visible | 0.393–0.759 μm | Photographic film; scanners with photomultiplier detectors; television. |
| Near infrared . . . | 0.759– 3 μm | Photographic film (to approximately 0.9 μm); scanners with infrared detectors. |
| Intermediate and far infrared. | 3.0 –1,000 μm | Scanners with infrared detectors. |
| Microwave, active (radar) and passive. | 0.1 – 100 cm | Scanning antennas with radio-frequency. |

¹ Far and “vacuum” ultraviolet wavelengths (0.004–0.280 μm) do not penetrate the Earth’s atmosphere significantly, so they are not useful for remote sensing. The portion of the electromagnetic spectrum generally used for remote sensing ranges from 0.3 μm (near-ultraviolet) to 3 cm (microwave/radar).

TABLE 2. — *Attributes of various parts of the photographic spectrum*

| Spectral region | Wavelength in micrometers (μm) | Characteristics |
|----------------------|---|--|
| Near ultraviolet ... | 0.315–0.393 | Good water penetration; good discrimination of rock and soil types; poor resolution (scattering); poor haze penetration; and weak shadows. |
| Violet | 0.393 (extreme visible) | Maximum water penetration (blue). |
| | .410 (mean) | Poor haze penetration. |
| Indigo | .440 (mean) | Poor resolution (scattering). |
| Blue | .470 (mean) | Weak shadows. |
| Green | 0.515 (mean) | Good resolution; peak of solar radiation; poor haze penetration; and moderate shadows. |
| Yellow | 0.560 (mean) | Fair resolution. |
| Orange | .620 (mean) | No water penetration. |
| Red | .700 (mean) | Fair haze penetration. |
| | .759 (extreme visible) | Strong shadows. |
| Near infrared | 0.759–1.0 | Fair to poor resolution; no water penetration; good haze penetration; and vegetation discrimination. |

TABLE 3. — *Utility of remote sensors for various types of soil mapping*

[VG, very good; G, good; F, fair; and P, poor. Leaders (...) indicate not applicable. Multispectral medium- and high-altitude airplanes, stereoscopic, and multiseasonal]

| Type of soil map | Conventional black-and-white air photos | Multispectral medium-altitude airphotos | Multispectral high-altitude airphotos | Multispectral Skylab photographs | Thermal infrared ¹ | SLAR |
|---|---|---|---------------------------------------|----------------------------------|-------------------------------|------|
| Soil associations (1:125,000 to 1:250,000 scale) | F | F–VG | F–G | P–F | P | P |
| Soil capability for agriculture (general map) | F–G | F–VG | F–G | P–F | P | P |
| Soil depth | F–G | F–G | P–G | P–F | P | P |
| Favorable and unfavorable topography | G–VG | VG | VG | G | P | F–G |
| Saline and alkali soils | F–G | F–G | P–G | P–F | P | P |
| Nutrient-deficient soils | P–F | F–G | F | P–F | ... | ... |
| Toxic soils (for example, seleniferous) | P–F | F–G | F | P–F | P | ... |
| Poorly drained soils; soils liable to flooding | F–G | VG | VG | F–G | P–F | P–F |
| Excessively stony soils | F–G | VG | F | F–P | P | F |
| Excessively clayey soils | F–G | VG | F–G | P–G | G | F–P |
| Soils with deficient moisture-holding capability | F–G | VG | G | P–F | P–F | P–F |
| Soils with hardpan problems | F–G | F–G | F–G | P–F | P | P |
| Erosion damage | G | VG | G | P–F | P | P–F |
| Erosion hazard (potential erodibility) | F–G | F–VG | F–G | F–G | P | P |

¹ At optimum time of year and time of day.

PHOSPHATE ROCK DETECTION USING SOLAR-STIMULATED LUMINESCENCE

By Robert D. Watson

Sedimentary phosphate rock is an increasingly important raw material for production of agricultural fertilizer. A common problem in prospecting for this material, however, is that cursory field

observation reveals few physical properties that distinguish phosphatic from nonphosphatic beds. Although small hand-carried ultraviolet lamps have been used to stimulate luminescing minerals and rocks, these methods of prospecting are limited because the lamps are low powered, the effective range is limited to a meter or less, and the work must be conducted at night because the low-intensity luminescence is obscured by bright sun-

light. An instrument, called an FLD (Fraunhofer Line Discriminator), has been recently developed that overcomes the above-mentioned difficulties and measures solar-stimulated luminescence at several orders of magnitude below the intensity detectable with the human eye. To assess the application of the FLD in prospecting for phosphate rocks, the luminescence of sedimentary phosphate rock samples from several geographic locations was measured using a laboratory fluorescence spectrometer at the 486.1-, 589.0-, and 656.3-nm wavelengths. Luminescence at the 486.1-nm Fraunhofer wavelength exceeded that at 589.0 and 656.3 nm, and the luminescence of all samples was within the sensitivity limits of the FLD and indicated the need for a field test.

A high-grade phosphate deposit crops out near Pine Mountain, northeast of Santa Barbara, Calif., in the upper part of the Santa Margarita Formation (Miocene), where a 24-m-thick phosphate zone occurs in siltstone and siliceous shale. The FLD was flown aboard a HU1B helicopter over the Pine Mountain area on November 26, 1974, at a hover altitude of 50 m. Luminescence measurements of phosphate rocks and soil, background rocks and soil, and vegetation along Chorro Grande Canyon were obtained at the 486.1-nm Fraunhofer wavelength. Phosphate rocks and soils were found to average 3.2 and 2.7 times more luminescent than background rocks, soil, and vegetation and were readily detected with the FLD. Future experiments are planned for FLD measurements of the luminescence of phosphate rocks in other areas from a fixed wing aircraft.

SUMMARY OF RECOMMENDATIONS FROM ABSTRACTS AND DISCUSSIONS OF PAPERS

The following recommendations, listed by subject, were made in the foregoing abstracts, during discussions of the papers, and by our invited participants in their presentations. Further recommendations are made in the next section, "Workshops."

FERTILIZER MATERIALS

PHOSPHATE

1. A worldwide appraisal of phosphate rock resources must be made. Phosphate is one of the three major fertilizer constituents, but

its worldwide abundance is less than that of either potash or nitrogen. Although present known reserves of phosphate are abundant, the long-term future of the fertilizer industry, and therefore of the world's food-producing capacity, is limited to the discovery and proper management of its phosphate resources.

2. Research should be initiated to develop theories of origin for all types of phosphate deposits. New information and new concepts on which to base additional working hypotheses are needed. Too much reliance on a single concept in exploration could result in failure to locate important deposits.
3. Research is recommended on the problem of phosphate fixation in soils rich in oxides of iron, manganese, and aluminum. The possibility should be explored of adding some substance to phosphate fertilizers that will allow the phosphate to stay free of fixation.
4. Phosphate data should be plotted on paleotectonic maps.
5. More research is needed on the occurrence of apatite in igneous and metamorphic rocks.
6. Investigations to determine the possible metamorphic equivalents of sedimentary marine phosphate deposits are needed.
7. More overseas work on phosphate deposits is desirable.
8. Further work should be done to characterize the extent of the Western phosphate field.
9. Work is needed to determine the relationships between the altered and unaltered phosphate rock in the Western phosphate field.
10. Geophysical techniques need to be developed for the exploration of phosphate deposits.
11. Geochemical techniques need to be developed for exploration for phosphate.
12. The U.S. Geological Survey should publish more open-file maps of phosphate areas.
13. Research is needed to determine factors controlling ore deposition on a small to medium scale (2 km or less).
14. The phosphate industry could benefit from a large, comprehensive publication that would bring recent work up to date in a single book.
15. The potential of the FLD (Fraunhofer Line Discriminator) as an instrument for prospecting for outcrops of phosphate rock should be investigated.

POTASH

1. More general research is needed on potash and related evaporites in the United States and worldwide.
2. More research should be done to determine the existence of an eastward trend of the New Mexico potash deposits.
3. Geophysical techniques need to be developed for exploration of potash deposits.
4. Better geochemical techniques for exploration of potash deposits are needed.
5. Efforts should be made to promote resource development of potash.
6. Research to determine the controlling factors for potash ore deposition on a small to medium scale (2 km or less) should be done.
7. Economic geologic studies of potash are needed.

SULFUR

1. A worldwide inventory of available sulfur sources should be made to indicate areas of deficiency.
2. Economic geologic studies of sulfur are needed.

SOIL AMENDMENT MATERIALS

1. The proposal has been made that volcanic ash and other pyroclastic materials, many of which are rich in glassy components, would decompose fairly rapidly and would, therefore, be an excellent soil amendment material. The texture of these materials could also improve the physical properties of soils. The geologist can indicate the varieties of young pyroclastic materials and the accessible deposits. A careful assessment of the current knowledge of natural volcanic-ash soils may provide an idea of the benefits to be expected from the addition of such material to normal soils. The decomposition of glassy rock materials in various soils and climatic environments should also be studied. The rates of release of various elements and in what form they are released are necessary information. The critical answers, however, await results of controlled field trials by agronomists and soil scientists.
2. Peat and other natural organic materials are very useful in certain types of agricultural applications. An inventory of these materials

is needed to assure a continuing supply as the demand increases.

3. Maps should be prepared that show the distribution of agricultural limestone, dolomite, and gypsum. As the use of these materials increases, the most efficient distribution systems will depend on complete knowledge of the sources of these materials.
4. An effort should be made to locate the sources of any type of potential soil amendment materials and to characterize them in terms of their chemical and physical properties.
5. It is recommended that the U.S. Geological Survey prepare an inventory of worldwide sedimentary zeolite resources with special emphasis on the countries of Southeast Asia and Central and South America.
6. Compilations of resources of bulk commodities such as sand and gravel, limestone, and gypsum should be coordinated with and done in cooperation with the State geological surveys.

WEATHERING OF ROCKS, SOILS, TRACE ELEMENTS, AND PLANT NUTRITION

1. Geochemical surveys should be made of the major soil types, worldwide, to identify those soils of greatest potential for particular crops.
2. Lithologic maps of surficial materials should be made to determine the mineralogy (primarily silicates and clays), grain-size distribution, permeability, and total element chemistry.

RELATED STUDIES

1. A worldwide computer inventory should be established for fertilizer and soil amendment materials.
2. Various remote sensing techniques should be investigated for use in mapping soil types and their distribution.

GENERAL RECOMMENDATIONS

1. Resource development of all of the fertilizer and soil amendment materials should be promoted.
2. Public education in the field of all mineral commodities is needed.

3. The U.S. Geological Survey should establish briefing sessions for members of Congress on the status of all mineral commodities.
4. The U.S. Geological Survey should write more reports on fertilizer commodities.
5. The U.S. Geological Survey should do more mapping of surficial materials—soil maps.
6. The U.S. Geological Survey should initiate more ground-water studies relative to problems in agriculture. Such studies could include leaching of elements from soils, redistribution or concentration of certain elements in soils, and residence times of fertilizer elements in soils.

WORKSHOP SESSIONS

REPORT FROM THE FERTILIZER MATERIALS WORKSHOP

R. P. Sheldon, Chairman
R. F. Meyer, recorder

INTRODUCTION

About 30 participants entered into the workshop deliberations on the final day of the Geology and Food Conference. The expertise of the participants included mineral economics, economic geology, fertilizer mineral petrology, physical oceanography, mineral extraction, beneficiation and production, Federal land management, data processing and systems analysis, and Federal science administration. Participants represented private industry, academia, and the Federal government.

The questions probed at the workshop related to present and potential shortages of the fertilizer minerals both on the world market and in local economies, and also related to ways these shortages might be alleviated by U.S. Geological Survey programs directed at new commodities as well as at better understanding of the distribution of presently used commodities.

This report presents generalizations about the problems of the fertilizer minerals, then deals individually with the specifics of each commodity, and finally presents recommendations for future U.S. Geological Survey programs.

ECONOMIC AND GEOLOGIC INFORMATION REQUIRED FOR THE MINERAL SUPPLY SYSTEM

The mineral supply system for any mineral is a complex multilateral system that (1) functions within governmental laws and regulations and hence is directed by public policies, (2) requires economic data and analysis in order to set both public and private industry policies, (3) requires geologic data and analysis in order for industry to formulate exploration and exploitation plans and for government to manage lands under its jurisdiction and carry out its other responsibilities, (4) requires continued basic research in the origin of mineral deposits and in new techniques of exploration and exploitation in order for reserves to be renewed from the undiscovered and subeconomic resources of the country as they are depleted, (5) requires reserve and production analysis in order to project short-term mineral availability, and (6) requires resource and exploration analysis in order to project long-term mineral availability and to understand the long-term viability of the total mineral supply system. These six requirements suggest programs, mostly within the jurisdiction of the U.S. Geological Survey, that must be carried out to insure effective working of the mineral supply system. These programs may be categorized as follows:

1. Economic studies of mineral demand.
2. Geologic¹ study of the commodity, including:
 - a. Field studies of known deposits to determine the geologic parameters controlling the local and regional distribution of the deposits;
 - b. Laboratory studies to determine the geochemistry and mineralogy of the commodity; and
 - c. Analogue studies of modern environments to understand processes of formation of commodities.
3. Geologic studies of little-known but potentially mineralized areas leading to resource appraisal and exploration-target identification.
4. Research in exploration techniques.
5. Resource analysis to project long-range mineral supply.

¹The term geology is used in its broad sense in this report and includes geochemistry and geophysics.

Depending on the character of the commodity, program needs vary between the last four program elements. However, economic studies of mineral demand are needed equally because of the interdependence of individual fertilizers in agricultural fertilizer application programs. Thus, this subject is treated separately.

FERTILIZER MINERAL DEMAND

The U.S. Geological Survey has no direct role to play in economic studies of the demand for fertilizer minerals within the Department of the Interior. That role is carried out by the Bureau of Mines. However, it is essential for the U.S. Geological Survey to be aware of changes in demand caused by changing agricultural technology and national and international economic trends. In order to set meaningful priorities, to establish realistic justification of geologic studies, and to usefully categorize resource estimates, not only the quantitative but also the qualitative demand for commodities must be known. The deleterious as well as the beneficial materials occurring with the fertilizer mineral resources must be appraised in order that they may be economically evaluated.

The above considerations make it essential that the U.S. Geological Survey develop sufficient expertise in mineral-demand economics to be able to understand such studies and to interact with the organizations responsible for them.

The workshop participants recognized that a better understanding of the quality categories of phosphate rock and the potential coproducts of various deposits must be established. Also, a long-term-demand study of potash would be helpful to set priorities for study of deposits that are presently uneconomic due to unfavorable mineralogy.

NITRATES

The present supply of nitrate fertilizer is based on air as a nitrogen source and natural gas as an energy source for nitrogen fixation. The limiting mineral in nitrate fertilizer production is natural gas, and consideration of its supply was beyond the scope of the workshop. In this context, however, several geologic studies of nitrogenous materials could be carried out.

Natural nitrates of consequence are known to occur only in Chile. G. E. Erickson of the U.S. Geological Survey has recently completed a long study of these deposits; he has demonstrated that

the deposits are probably unique in the world and constitute only a small resource in relation to present world demand. From the standpoint of mineral supply, no present justification exists for further USGS study. However, the origin of these deposits is still in doubt, and a fuller understanding might lead to discovery of a natural process of nitrogen fixation that requires less energy than present processes.

The main compound of nitrogen in fertilizer production is urea, and its production need not depend on natural gas. Carbon dioxide and nitrogen in air can be combined to form urea. This possibility should be pursued to establish the time frame of its economic feasibility. The resources of CO₂ in nonmethane natural gas wells in the United States should be appraised. Sufficient data presently exist in the U.S. Geological Survey to quickly make a preliminary appraisal.

Combined nitrogen occurs in oil shale and crude oil, and this occurrence should be studied to establish its feasibility as a source of nitrate.

Buddingtonite, an ammonium-bearing feldspar, has been discovered in abundance in the Phosphoria Formation in southeastern Idaho. Although it is in a relatively insoluble mineral form, its resources should be estimated and fertilizer scientists should be made aware of its existence. Also, other phosphate deposits of marine origin should be examined for similar occurrences, particularly young deposits which, instead of buddingtonite, may contain an ammonium-rich zeolite that probably would be a valuable fertilizer and soil amendment material.

Programs of study of potentially mineralized areas, exploration research, and resource analysis should await results from the above studies of the geology of nitrates and CO₂.

POTASH

GEOLOGY OF POTASH

Potash is concentrated in saline waters and deposited as evaporite minerals, so its origin is no mystery. However, the processes of chemical sedimentation are imperfectly understood, particularly with respect to basin fluid dynamics and geochemical processes attending surficial evaporation. Three kinds of modeling studies are needed to enlarge the geologic understanding of the basinal distribution of potash deposits.

First, geologic facies studies of rocks containing potash need to be carried out to develop conceptual sedimentation models based on real deposits.

Second, these conceptual models should be used as the basis of computer modeling. Or, to put it another way, the conceptual models should be tested by computer modeling.

Finally, actual-scale modeling should be carried out in arid areas to test the results of the first two modeling studies.

RESOURCE APPRAISAL

Potash deposits are known in the United States, but some are not well appraised. Also, some possibilities exist for additional discoveries. In particular, the following program opportunities exist:

1. Potash deposits of eastern New Mexico and western Texas probably contain only polyhalite, but the resources are only poorly known. The future demand for polyhalite needs to be determined, as its sulfate content may make it valuable in some fertilizers. It is also possible that the dissemination of knowledge of a large resource of polyhalite to industry could stimulate its demand.
2. The Michigan basin seems to offer a potash potential that is too poorly known at present to evaluate.
3. The salt domes of the Gulf Coast have not been properly studied for potential potash content.

Although workshop participants discussed the need for a computerized resource data bank only in relation to phosphate, it is equally urgent that such a data bank, including all deposits throughout the world, be developed for potash. Not only should identified resources be listed in the data bank, but the undiscovered resources should be appraised and entered in the bank. This is an essential step to analyzing the long-term availability of potash.

EXPLORATION RESEARCH

Further study of bromine-chloride ratios needs to be made to improve this exploration technique.

A major deterrent to better exploration technology is the difficulty of accurately logging drill holes. Geophysical research in this area could greatly improve present techniques.

RESOURCE ANALYSIS

The long-term availability of potash must be determined in relation to long-term demand esti-

mates. This determination involves analyzing the undiscovered resources by search and occurrence modeling. Thus, a family of projections of future supply can be constructed using varying assumptions of future prices and costs (including the external costs), exploration technology, and mining and recovery technology.

SEDIMENTARY PHOSPHATES

GEOLOGY OF PHOSPHATE

Although much research has been carried out on the genesis of sedimentary phosphorite, the problem is complex enough and the data are sparse enough to allow multiple genetic interpretations for even the better known deposits. These differing hypotheses of origin lead to differing exploration strategies, so it is important that more research be carried out on the subject.

The geochemical cycle of phosphorus—from igneous apatite petrology through the weathering and transportation phases to sedimentation—needs better definition. Particularly important is more precise consideration of mass balance of the cycle. This study must be based on better data of the geochemistry of phosphate in the lithosphere.

The mineralogy and geochemistry of sedimentary apatite are still poorly understood in terms of defining the range of natural compositions and mineral structures and the chemical processes of formation. Further laboratory research on these subjects is needed.

Stratigraphic and sedimentologic research on at least four phosphate-bearing formations needs to be continued in order to derive more accurate sedimentologic models from them. These include the Miocene rocks of southern California, the Permian rocks of the Rocky Mountains, the Tertiary rocks of the Atlantic Coast, and the Precambrian phosphorite and related rocks in Rajasthan, India.

Phosphatic sediments have been found on the sea floor, largely in areas of coastal upwelling, as the result of widespread bottom sampling in all oceans. This environment should be studied in detail to better understand the controls and character of the sedimentation of phosphatic and related sediments. The best opportunity for study is offshore Baja California, but the continental shelves of Peru and of Northwest and Southwest Africa are also reported areas of phosphatic sediments. In addition, a study of other marine

sedimentary environments, such as the Atlantic shelf of the United States, the Bass Strait, the Chatham Rise, and selected seamounts in the tropical northeast Pacific Ocean could contribute to an understanding of the conditions under which the Miocene phosphorites of the Southeastern United States were deposited. A number of the existing hypotheses of origin could be tested and sharpened by such marine sediment studies.

Finally, the models of marine phosphate sedimentation, conceived from ancient rock studies and supported by laboratory and marine geologic studies, should be computer modeled to develop a better predictive capability for use in phosphate prospecting.

RESOURCE APPRAISAL

The major phosphate deposits of the United States are the Miocene and Pliocene deposits of the Southeastern United States, mainly Florida and North Carolina, and the Permian deposits of Idaho and adjacent States. The phosphate resources of the Southeastern United States are fairly well appraised although some regional overview studies could be profitably made, particularly if company data could be made available. The Permian deposits of the West badly need to be appraised. This would consist largely of analyzing and synthesizing existing data, although some additional geologic mapping should be undertaken.

In addition, some phosphate is known to exist in other areas, particularly Alaska and the Great Basin, and should be better appraised.

A phosphate data bank should be established internationally at the earliest opportunity. The necessary computer format and software have already been developed for coal resources and could be readily adapted to a phosphate data bank. An informal international group of geologists interested in phosphate has been in existence for some years. Preliminary discussions among this group indicate that building such a data bank not only would be feasible but would be undertaken enthusiastically. The data bank would contain not only data on well-studied large deposits but also data on occurrences of phosphate deposits that are not economic. It would constitute an objective basis for the appraisals of undiscovered resources that are necessary for national and world planning. National and multinational development organizations might be interested in financially supporting this project.

EXPLORATION RESEARCH

Preliminary studies have revealed that the FLD (Fraunhofer Line Discriminator) is a very promising exploration technique. This geophysical airborne instrument would work particularly well in areas of arid climate where little vegetation is present. Further development would be warranted and could be carried out in Baja California or in several other desert areas of known phosphate occurrences.

Studies of the fate of weathering products of phosphorite and their occurrence in ground water should be carried out. These include fluorine, helium, and perhaps trace metals.

RESOURCE ANALYSIS

The projections of long-term availability of phosphate should be made in a similar manner as that described for potash.

IGNEOUS APATITE

The discovery of igneous apatite in some parts of the world has been increasing in recent years, and a short study of the feasibility of discovery of igneous apatite in the United States should be undertaken.

SULFUR

A short study of the future requirements of sulfur should be made and, if the requirements are significant, a follow-up study of the feasibility of discovering U.S. sulfur deposits should be made.

REPORT FROM THE SOIL AMENDMENT AND ROCK WEATHERING WORKSHOP

Jon J. Connor, Chairman
Richard A. Sheppard, Recorder

Considerable discussion took place in the first part of the workshop as to what materials are suitable for soil amendments. A tentative list included peat, volcanic ash, zeolites, fly ash, basic slag, gypsum, limestone, garbage, sewage, humates, sand, clay, and mine tailings. An attempt was made to rank these in order of importance, and although this was not accomplished for all materials, it was agreed that limestone and gypsum should be near the top of the list.

The primary objection raised against large-scale application of such common amendments was economic. In order to substantially improve large areas of poor soil through amendments, incredibly large quantities of the amendments must be transported from "source" areas to "need" areas. The tremendous energy requirements of distribution, whether long-distance or local (spreading it on large acreages of tillable soil) seem prohibitive. This fact was brought out in a lengthy discussion on the present and potential uses of peat. Its agricultural uses are primarily in "truck garden" crops, but the relatively low cost-benefit ratio involved in widespread redistribution accounts for the fact that it is not widely used in large-scale farm crops.

That realization forces one to look at improving use of the amending materials in place. This, in turn, calls for an up-to-date inventory of the world's "good" soils. In this respect, most of the discussion was devoted to various types of mapping that could be done. It was emphasized that we need more and better maps of surficial deposits. Such maps should include the types of materials, the depth to bedrock, the physical properties, and perhaps the depth to the water table. The need for large-scale maps of surficial deposits was emphasized, and it was stated that such maps should be lithologic rather than genetic.

The discussion of maps continued with a listing of numerous kinds of so-called "nutritional" maps. Some examples follow:

1. Types of amendment materials.
2. Depth to bedrock.
3. Soil physical properties.
4. Depth to water table.
5. Salt seeps.
6. Limestone.
7. Gypsum.
8. Dolomite.
9. Land-use planning.
10. Element distribution.
11. Toxic element.
12. Beneficial element.
13. Hard pan.
14. Peat map.
15. Volcanic ash.

Some research areas were also recommended. It was suggested that, to better understand the geochemistry of soils, the U.S. Geological Survey could study the release of elements to soils from

the primary minerals in the soils. In connection with this, the release of elements from fertilizers in the soils and the behavior of elements during weathering in general should be studied.

The most important result of the discussion was a general recognition that the group could not agree on a common approach to geologic work in the subject area of soil amendments. This lack of consensus reflected, in part, the natural desire of the individual participant to "push" his own particular interests; but, more fundamentally, it reflected the unspoken awareness that soil problems in terms of food production are by their nature agronomic rather than geologic. Four points kept recurring through the discussion. These are the need for (1) better data banks, (2) bibliographies, (3) better maps, and (4) better and more interdisciplinary communication.

CURRENT USGS PROJECTS

The following is a current list of USGS projects that have direct or indirect application to research related to agricultural problems. They are arranged under the following categories:

1. Fertilizer materials.
2. Soil amendment materials.
3. Weathering of rocks, soils, trace elements, and plant nutrition.
4. Land use.

The projects in the categories of fertilizer materials and soil amendment materials apply directly to research related to agriculture.

The projects under weathering of soils, trace elements, and plant nutrition are both directly and indirectly related. For instance, some projects involve studies of trace elements in soils for the purpose of developing exploration techniques for finding metallic ore deposits in the bedrock beneath the soils. The basic data, however, can be applied to studies of soil chemistry.

The projects under the subject of land use derive much data which can be used in agricultural applications. Such information as determination of soil types, water supply, surface drainage, steepness of slopes, distribution of glacial deposits, flood-prone areas, and natural vegetation; problems of erosion and land utilization; and areas of potential strip mining and urban development are examples of

the types of data that have or could have an impact on agricultural development.

FERTILIZER MATERIALS

Subject: Phosphate

Title: Phosphate in Southeastern United States, 9430-00139

Project Chief: J. B. Cathcart

Economic geology and resource appraisal, reserves, stratigraphy, structure, mineralogy, chemistry, origin of deposits.

Subject: Phosphate

Title: Petrology and geochemistry of Phosphoria Formation, 9430-00137

Project Chief: R. A. Gulbrandsen

Emphasis on chemical composition, mineralogy, and petrography of phosphorites and phosphatic rocks; CO₂, Sr, and Y determinations on apatite; environmental impact work.

Subject: Phosphate

Title: Great Basin phosphate, 9430-01346

Project Chief: K. B. Ketner

Stratigraphy of phosphatic rocks and their relation to Phosphoria Formation in Idaho, phosphate reserves and origin, relation of Phosphoria sea to oceanic upwelling, quadrangle mapping.

Subject: Phosphate

Title: California phosphorites, 9430-01578

Project Chief: A. E. Roberts

Phosphate content of selected marine units having future phosphate potential—for example, Monterey Formation; stratigraphic and areal distribution of phosphorites; chemical and mineralogical composition; physical, chemical, and biological environments of phosphorites, including diagenetic effects and localization of phosphates; mapping.

Subject: Phosphate

Title: Geologic map of Wyoming, 9530-00544

Project Chief: J. D. Love

Compilation of geologic map of Wyoming; mapped the distribution of the Phosphoria Formation.

Subject: Phosphate—Stratigraphy and structure of southeastern Idaho.

Title: Snake River Plain, 9530-00873

Project Chief: Steven S. Oriel

Mapping of upper Paleozoic rocks (including Phosphoria Formation) in the ranges southeast of the

SNAKE RIVER PLAIN; consulting with Conservation Division on public lands in Idaho withdrawn for phosphate; consulting on multiagency assessment of environmental impact on Federal phosphate lands.

Subject: Potash

Title: Mineralogy of nonmetallic deposits, 9430-00141

Project Chief: B. M. Madsen

Emphasis on mineralogy, petrography, and chemical composition of salines and related rocks; low-temperature and pressure alteration of sediments; support work for other projects.

Subject: Potash

Title: Paradox basin salt studies, Utah-Colorado, 9430-00146

Project Chief: O. B. Raup

Development of a physico-chemical model of basinal evaporite deposition; origin of potash deposits and associated petroleum and metallic mineral deposits; surface and subsurface stratigraphy, structure, and lithofacies analysis; petrography; mineralogy; geochemistry.

Subject: Potash

Title: New Mexico potash studies, 9430-00153

Project Chief: C. L. Jones

Geology and resource evaluation of Permian potash deposits in southeastern New Mexico; surface and subsurface study of distribution, lithology, structure, and history of the deposit.

Subject: Study of sulfur accumulations

Title: Sulfur in coal, lignite, and peat, 9420-01092

Project Chief: Alfred J. Bodenlos

Investigation of the paleoenvironments and geochemistry leading to the accumulation of sulfur in coal; compilation of sulfur tonnages in coal, a potential resource of elemental sulfur or sulfuric acid when recovery systems are developed; Project Chief also serves as USGS sulfur commodity geologist.

SOIL AMENDMENT MATERIALS

Subject: Lightweight aggregates as soil amendments

Title: Lightweight aggregate resources of the United States, 9350-00171

Project Chief: Alfred L. Bush

Appraisal and assessment of the reserves and resources of lightweight aggregate materials for the entire United States; changes in uses, consumption patterns (geographic and economic), technology, and energy requirements; delineation of favorable areas for exploration and development of guides to ore for the numerous kinds of suitable materials.

Subject: Humate as a soil amendment
Title: Geology and geochemistry of coal and humate, 9420-00106

Project Chief: Vernon E. Swanson
Primary emphasis currently on chemical composition and geochemical genesis of coal, particularly trace elements, based on complete analyses of 3,800 samples from 36 States; determination of the progenitors and processes of alteration of humic organic materials in sedimentary rocks, and especially identification of the processes of mobilizing, transporting, and precipitating soluble organic substances and the associated metals (Cu, Ni, U, etc.) concentrated in humates; distribution, approximate tonnages, lithologic associations, and stratigraphic relations of humate deposits—for example, humate sands in north Florida and eastern South Carolina, and leonardite in North Dakota, Wyoming, and New Mexico.

Subject: Zeolites as soil amendments
Title: Zeolites in southeastern California, Arizona, and Oregon, 9430-00164

Project Chief: R. A. Sheppard
Formation and distribution of zeolites and authigenic silicate minerals in Cenozoic lacustrine deposits of the Western United States; comparison and correlation of optical and cell parameters of natural zeolites with variations in chemical composition; geochemistry and mineralogy of unusual hydrous silicate deposit in Trinity County, Calif.

Subject: Bentonite as a soil amendment
Title: Bentonite resources in the Rocky Mountain region, 9430-01288

Project Chief: C. A. Wolfbauer
Determination of physical, chemical, and mineralogical properties of bentonite; stratigraphic, geographic, and environmental distribution; relationship of physical properties to chemical and mineralogical composition; Na:Ca exchangeable ion ratios.

Subject: Volcanic ash (pyroclastic material) as soil amendments

Title: Volcanic ash chronology, 9720-00324

Project Chief: Ray E. Wilcox

Development of methods and criteria for use of volcanic ash beds as time-stratigraphic markers in upper Cenozoic deposits; correlations based on determinations of chemical, optical, and weathering characteristics of the constituents of the ashes.

Subject: Peat as a soil amendment

Title: Peat studies, 9360-00254

Project Chief: Cornelia Cameron

Exploration of peat deposits suitable for soil-conditioner and horticultural use by field study in areas representing major terrane types typical of the United States; discovery of physiographic and geologic controls of deposit occurrence and size; determination of relation of stratigraphy and ecology to water movement and diagenesis affecting peat quality; cataloging of major deposits according to ASTM standards for current agricultural uses and anticipated uses in manufacture of foodstuffs and pollution controls.

WEATHERING OF ROCKS, SOILS, TRACE ELEMENTS, AND PLANT NUTRITION

Subject: Soils

Title: Quaternary dating techniques, 9530-01559

Project Chief: Kenneth L. Pierce

Studies of thick sections of loess showing several buried soils that are more developed than the surface soil; fission-track dating.

Subject: Surficial geology and geochronology

Title: Methodology of Quaternary dating techniques, 9530-01937

Project Chief: George O. Bachman

Evaluation and application of various radiometric, stratigraphic, and geochemical techniques for dating surficial deposits, with emphasis on soil-forming processes in the arid environment.

Subject: Soils

Title: Geotechnical measurements and services, 9550-00645

Project Chief: Harold W. Olsen

Tests and analyses of soils and rocks in support of

research projects of an engineering geology nature; engineering soil property tests including size analysis, Atterberg limits, specific gravity, porosity, moisture-density relationships, pH determinations, volume change, and compressive, shear and bearing strengths.

Subject: Geochemistry of the Earth's crust

Title: Data of geochemistry, 9760-00429

Project Chief: Michael Fleischer

Provides major reference source for element abundances in the Earth's crust, including geologic materials used as fertilizers and physical soil amendments.

Subject: Analytical services, food and feed plants

Title: Plant laboratory support, 9760-00433

Project Chief: T. F. Harms

Provides special methods necessary for chemical analysis of plant materials, including food and feed plants.

Subject: Rock, soil, and plant data storage and retrieval

Title: Geochemical data systems, 9760-00440

Project Chief: R. V. Mendes

A basic data bank for chemical analyses, including composition of rocks and native and cultivated soils and plants.

Subject: Geochemistry of surficial materials, including soils

Title: Urban geochemistry, 9760-00512

Project Chief: Harry A. Tourtelot

Effects of geologic formations and urban pollution on chemical constituents of urban and agricultural soils, and effects of sewage-sludge applications on crop lands.

Subject: Chemical elements in rocks and displaced geologic materials

Title: Western coal regions rocks, 9760-01135

Project Chief: R. J. Ebens

Establishment of geochemical baselines for range and crop lands subject to disturbance by mining operations.

Subject: Chemical elements in natural soils and mine spoil

Title: Western coal regions soils, 9760-01136

Project Chief: R. R. Tidball

Establishment of geochemical baselines for soils to

use in assessing chemical changes produced by effects of coal exploitation on crop and range lands.

Subject: Chemical elements in native vegetation and crop plants

Title: Western coal regions plants, 9760-01137

Project Chief: J. A. Erdman

Establishment of geochemical baseline data for shrubs, range grasses, and grains in relation to effects of present and future coal-mining operations; revegetation and reclamation of mine spoil.

Subject: Bioavailability of trace elements to plants

Title: Element availability, soils, 9760-01876

Project Chief: R. C. Severson

Identification of those chemical properties of soil substrates that best predict the trace-element content of rooted plants.

Subject: Bioavailability of trace elements to plants

Title: Element availability, plants, 9760-01877

Project Chief: L. P. Gough

Distribution and translocation of trace elements in plant tissue.

Subject: Studies of scavenging by Fe, Mn oxides, in part immobilizing metals

Title: Research in methods of chemical analysis for geochemical exploration, 9330-00085

Project Chief: T. T. Chao

Research topic: Hydro- and biogeochemistry of heavy metals.

Principal Investigator: T. T. Chao

Scavenging of various metals by Mn and Fe oxides.

Subject: Studies of scavenging by Fe, Mn oxides from ground waters

Title: Surface and ground waters in geochemical exploration, 9330-00087

Project Chief: Gary A. Nowlan

Research topic: Anomaly characterization

Principal Investigator: Gary A. Nowlan

Study of scavenging of metals from surface water and bed-flow water by Fe, Mn oxides and development of devices for sampling streambeds that would be useful in water-quality and irrigation studies.

Research topic: Hydrogeochemistry as a tool used in the search for metals

Principal Investigator: W. R. Miller

Use of natural water and its trace metal content to develop a tool for mineral-deposit location and identification.

Subject: Studies of scavenging by oxides, in part immobilizing metals

Title: Geochemical exploration research in desert, semidesert, temperate, tropical, and subtropical regions, 9330-00088

Project Chief: Robert E. Learned

Research topic: Geochemical exploration in lateritic territory

Principal Investigator: Wallace R. Griffiths

Degree of accumulation of metals in the uppermost soil zones—the root zone of most food plants and the zone that is enriched in metal through decay of plant material; lateral variations in total contents of some metals; combined geochemical-heavy mineral survey.

Research topic: Minor elements in detrital minerals

Principal Investigator: W. C. Overstreet

Limonite scavenging of uranium in the alkalic complex at Darby Mountain in stream beds; study of surficial processes, including agricultural, as means of working out history of sampled material; ties in with project 9330-00079.

Research topic: Basin Range exploration

Principal Investigator: Henry V. Alminas

Extensive geochemical maps showing distribution of the micronutrients Cu, Zn, Mo, and Co in surficial materials in south-central New Mexico; mineral sampling of plants.

Research topic: Research exploration geochemistry, Puerto Rico

Principal Investigator: Robert E. Learned

Soil profiles over porphyry copper deposits in Puerto Rico; areal geochemical maps of large areas, including, as usual, minor nutrients Cu, Co, Mo, and Zn.

Subject: General plant-soil interrelations

Title: Geochemical exploration research in arctic, subarctic, alpine, and subalpine regions, 9330-00089

Project Chief: J. Howard McCarthy, Jr.

Research topic: Geochemical investigation in alpine and subalpine environment

Principal Investigator: Gary C. Curtin

Interrelations between plant and soil metal contents in Colorado, Alaska, and Idaho; analysis of soils, humus, plants, and sediment in neighboring creeks. Gathering of much basic data on the ability of plants of various families to pick up nutrient metals in the three environments.

Research topic: Geochemical Exploration

techniques in the arid environment

Principal Investigator: Maurice A. Chaffee

Sampling of soils, stream and wash sediments, and plants; studies of important browse plants, minor in direct human nutrition.

Subject: General geochemical surveys of soil metals.

Title: Geochemical characterization of metallogenic provinces and mineralized areas, 9330-00093

Project Chief: George J. Neuerburg

Research topic: Geochemical exploration, Coeur d'Alene district

Principal Investigator: Garland B. Gott

Areal distribution of micronutrients of smelter as well as of natural origin.

Research topic: Geochemical exploration studies with selenium, tellurium, and thallium

Principal Investigator: John R. Watterson

Nutritional aspects of selenium and thallium—both toxic and beneficial as micronutrients.

Research topic: Accessory sulfides of igneous rocks

Principal Investigator: George J. Neuerburg

Alunite group of minerals and its phosphate and arsenate analogs; scavenging of Cu, Zn, Mo by hydrous iron and manganese in the alpine and subalpine environments.

Subject: Botanical studies

Title: Biogeochemical research in geochemical exploration, 9330-00099

Project Chief: John B. Cathrall

Research topic: Botanical research

Principal Investigator: Helen L. Cannon

Relationship of geochemistry and geobotany to public health problems, including nutrition.

Research topic: Elements in organic-rich materials

Principal Investigator: Fred N. Ward

Development and application of analytical methods useful with organic materials, food, and non-food plants.

Subject: Plant-soil interrelations in desert or semidesert environments

Title: Mexican Coop., 9330-01366

Project Chief: Paul K. Theobald

Research topic: General plant-soil interrelations in desert or semidesert environment

Principal Investigators: Glenn H. Allcott and Paul K. Theobald

Plant-soil interrelationships of Arabia, South Dakota, Arizona, and Mexico.

LAND USE

Subject: Environmental data

Title: Denver urban corridor studies, 9530-00555

Project Chief: Wallace R. Hansen

Emphasis on recasting geologic and hydrologic data into forms readily usable by nongeologists; production of maps and reports concerning land-use, nonmetallic mineral resources, climatology, geologic hazards, vegetation, natural and historic landmarks, trace elements, and flood-prone areas along the Front Range urban corridor of Colorado.

Subject: Environmental data

Title: Central Nebraska basin—Bedrock geology and thickness of overlying Quaternary deposits, 9530-00588

Project Chief: George E. Prichard

Data from the files of the Nebraska Geological Survey supplemented by the current test-well drilling program and reconnaissance field work being used to delineate the bedrock geology and determine the thickness of overlying Quaternary deposits, which consist of loess, fill, alluvium, and lake sediments; bedrock geology superimposed on a topographic base map at a scale of 1:250,000 and thickness of Quaternary deposits shown by isopach lines on map.

Subject: Environmental data

Title: Denver mountain soils, 9530-00861

Project Chief: Paul W. Schmidt

Study of suitability of mountain areas along the Front Range, Colorado, for homesites, road locations, underground utility corridors, waste-disposal sites, and ground-water recharge; relationship of distribution, thickness, and character of mountain soils to urbanization.

Subject: Surficial mapping

Title: Surficial—Snake River Plain, 9530-00871

Project Chief: William E. Scott

Reconstruct geomorphic events that produced such land resources as the arable land and unconfined artesian and perched ground-water aquifers; determine physical properties and age relations of unconsolidated materials; provide basis for evaluation

of engineering properties and material resources, such as foundation conditions for construction, water supply, waste disposal, and so forth; investigate problems of soil erosion.

Subject: Surficial mapping

Title: Black Mesa surficial geology and environmental study, 9530-01552

Project Chief: Thor N. V. Karlstrom

Surficial and environmental geology of an area of active strip mining, with special attention to late Pleistocene and Holocene climatic and geomorphic events.

Subject: Environmental data

Title: Dillon 2° sheet, Montana, 9530-01557

Project Chief: E. T. Ruppel

Geologic studies; potential for nonmetallic mineral and water resources; thickness of valley fills; and other environmental geologic topics as needed for land-use information.

Subject: Environmental data

Title: Geologic factors for mapping reclamation potential of western coal lands, 9530-01560

Project Chief: Harold E. Malde

Determination of reclamation potential based on measurement of such pertinent geologic, hydrologic, and geomorphic factors as variety and steepness of slope, diversity of landscape, conditions of erosion, density and character of surface drainage, and variations in soil and overburden.

Subject: Environmental data

Title: Environmental aspects of coal development, eastern Powder River Basin, Wyoming, 9530-01565

Project Chief: Donald A. Coates

Acquire, compile, and interpret basic land and resource data for environmental impact evaluation of large-scale surface mining of the thick Wyodak-Anderson coal bed along the eastern margin of the Powder River Basin in Wyoming.

Subject: Environmental data

Title: Energy lands—Oil shale, 9530-01598

Project Chief: Robert B. Raup, Jr.

Acquire and assemble a knowledge base of bedrock and surficial geologic data at regional scales

(1:250,000) and combine these data with hydrologic, topographic, soils, geochemical, resource, and related earth science data to define and cartographically display assessments of land capability.

Subject: Surficial mapping
Title: Environmental geologic studies, Kaiparowitz coal basin, Utah, 9530-01637
Project Chief: Kenneth A. Sargent
Surficial geologic mapping and compilation of land-use and geologic-hazard map folio.

Subject: Surficial geologic mapping
Title: Environmental geology of San Juan Basin, 9530-01932

Project Chief: Glenn R. Scott
Surficial geology and environmental mapping at 1:250,000 of the entire basin, and detailed mapping of strippable coal areas.

Subject: Surficial geologic mapping
Title: Environmental geology of Williston basin, 9530-01936

Project Chief: Donald E. Trimble
Surficial geologic mapping of coal lands of Williston basin, Montana and North Dakota, at 1:100,000 and 1:500,000, and environmental geologic studies of areas of strippable coal.

Subject: Environmental data
Title: Engineering geologic mapping research, Powder River Basin, 9550-01631

Project Chief: Frank W. Osterwald
Basic engineering geologic data to serve as background for land-use planning; surface and subsurface data on engineering properties and predictable behavioral characteristic of the surficial and bedrock units in the area; interpretations of the geologic and engineering data for the use of land-use planners, civil engineers, architects, and government officials.

Subject: Environmental data
Title: Denver metropolitan area, Colorado, 9550-00632

Project Chief: Robert M. Lindvall
Preparation of detailed general-purpose geologic maps of eight quadrangles covering the major part of the Denver area to provide basic information pertinent to maximum land utilization; engineering properties of the surficial and bedrock units,

areas subject to flooding, and location and extent of sand and gravel deposits necessary for construction aggregate materials.

Subject: Environmental data
Title: Geology of Salt Lake City and vicinity, 9550-00636

Project Chief: Richard Van Horn
Geologic mapping of the Salt Lake area with emphasis on surficial deposits; special purpose maps relating to specific environmental features including floodwater and surface-water information, relative geologic stability, thickness of loosely packed sediments and depth to bedrock, and minimum depth to water in shallow aquifers.

BIBLIOGRAPHY OF PUBLICATIONS BY U.S. GEOLOGICAL SURVEY AUTHORS THROUGH 1975 THAT PERTAIN TO SUBJECTS RELATED TO THE GEOLOGY AND FOOD CONFERENCE

Compiled by Flora K. Walker

FERTILIZER MATERIALS

GEOLOGY OF PHOSPHATE

This list of references covers 30 years of research in the U.S. Geological Survey in various subjects related to the geology of phosphate. The publications include such topics as stratigraphy, mineralogy, geochemistry, and economic geology.

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SOIL AMENDMENT MATERIALS

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LAND-USE MAPS

The workshop on Soil Amendment Materials concluded that a primary function of the U.S. Geological Survey that could contribute to the geology of agriculture is specialized geologic mapping. It was suggested that maps could be prepared that would show such things as types of soil amendment materials, depth to bedrock, distribution of soils and their various physical and chemical properties, depth to water table, distribution of limestone and gypsum, and many others.

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