Geological Survey Research 1960

Synopsis of Geologic Results

GEOLOGICAL SURVEY PROFESSIONAL PAPER 400-A

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THOMAS B. NOLAN, *Director*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 400

A synopsis of geologic results, accompanied by short papers in the geological sciences. Published separately as chapters A and B

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FOREWORD

The activities of the United States Geological Survey encompass projects that span the full range of the geological sciences. The volume and complexity of such a research program make it difficult to review, coordinate, and release the results of the work as quickly as is desirable; as a result considerable time normally elapses between the completion of many investigations and the publication of the final reports. And yet this same volume and complexity make it the more essential that some means be found to digest and make available to all the new ideas and new discoveries that have been achieved.

In an effort to help solve this problem the present volume has been prepared; it summarizes the results of the recent work of the Geologic Division of the Survey. The report consists of two main parts: Chapter A, "Synopsis of Geologic Results," is primarily a summary of important new findings, either as yet unpublished or published during the fiscal year 1960—the 12 months ending June 30, 1960. It also includes a list of investigations in progress during that period, along with the names and headquarters of those in charge of each, and a list of reports published or otherwise made available to the public during the same period. Chapter B, "Short Papers in the Geological Sciences," consists of 232 papers, generally less than 1,000 words in length. These are of two kinds. Some papers are primarily announcements of new discoveries or observations on problems of limited scope, regarding which more detailed and comprehensive reports may or may not be published later. Others summarize the conclusions drawn from extensive investigations that have been in progress for some time; these conclusions in large part will be embodied in much longer reports that will be published later.

This report is frankly an experiment. Although both chapters in this volume deal largely with the work of the Geologic Division, it is hoped to expand the scope of the report in future years to include results obtained by other Divisions of the Geological Survey, and to issue it annually. But whether this is done, and whether future issues will be in the same form as this one, depends on how well this volume achieves the purposes described above. Comments and suggestions from those who use the volume will be appreciated and will help determine the content of the future ones.

Thomas B. Nolan

THOMAS B. NOLAN,
Director.

PREFACE

The main activities of the Geologic Division of the Geological Survey may be grouped into three main categories, defined by the immediate objectives that motivate them: (a) economic geology; (c) regional geology; and (b) research on geological processes and principles. The work in the field of economic geology is aimed primarily at developing information that will be useful in the search for usable deposits of minerals and fuels, or help to solve problems connected with engineering works, such as the construction of highways and dams. It also provides the nation with an appraisal of its known and potential mineral resources. The regional studies determine the structure, composition, history, and distribution of the rocks that underlie the United States and other areas. Because this work is essentially exploratory in nature, its underlying purpose is also mainly economic, for it provides the basis for the broad appraisal of the potential mineral resources of undeveloped areas. The research on geologic processes and principles consists of observational, experimental, or theoretical investigations in the field and in the laboratory, aimed at improving our understanding of geologic processes and principles and hence developing and extending the usefulness of the geologic sciences. In addition, an important part of the Division's work consists of services to other Federal agencies that either do not have geologic staffs of their own or that require some of the special skills of the Division's scientists.

Nearly all of the Division's activities yield new data and principles valuable in the development or application of the geologic sciences, and it is the purpose of chapter A to summarize the highlights of important findings that have come to the fore during fiscal year 1960. Some of these have been published or placed on open file during the year, some are published in chapter B of this volume, and some have not yet been pubpublished elsewhere at all. Only a part of the results released during this period can be reported here, even in summary fashion, and the reader who needs more complete and detailed information will wish to consult the publications listed on pages A107–A127 and the papers in chapter B.

A comprehensive list of investigations in progress is given on pages A76–A106, with the names and addresses of those in charge of them, in the hope that it may prove helpful to those interested in work in progress in various areas or topics.

The results summarized here are presented in several categories based on the immediate objectives of the work or its applicability to some special field. Those results that have mainly to do with economic problems are described on pages A1–A26; results that bear mainly on the geology of specific regions are given on pages A26–A54; and those that deal mainly with principles, processes, and methods of general interest are discussed on pages A54–A73. Although this classification of subject matter is a familiar one, it is nevertheless overlapping—an investigation stimulated by economic objectives may also yield important results in the fields of regional and theoretical geology, and so on. Limitations of both space and time prevent us from including an index to chapter A, but general cross-references are given at appropriate places in the text. We hope that these, together with the table of contents, will guide the reader to the topic in which he is most interested. The short papers of chapter B are arranged topically and in addition are accompanied by a short index.

During fiscal year 1960, the Geologic Division's services were utilized by and financially supported to some extent by the following organizations:

Federal Agencies:

- Air Force—Cambridge Research Center
- Air Force—Technical Application Center
- Army—Corps of Engineers
- Army Engineer Research and Development Laboratory
- Army—Waterways Experiment Station
- Atomic Energy Commission—Division of Biology and Medicine
- Atomic Energy Commission—Division of Reactor Development
- Atomic Energy Commission—Military Application Division
- Atomic Energy Commission—Raw Materials Division
- Atomic Energy Commission—Research Division
- Atomic Energy Commission—Special Projects Division

Bureau of Indian Affairs
Bureau of Mines
Bureau of Land Management
Bureau of Public Roads
Bureau of Reclamation
Department of Agriculture
International Cooperation Administration
National Institutes of Health—Cancer Institute
National Park Service
National Science Foundation
Navy—Bureau of Docks
Navy—Office of Naval Research
Office of Minerals Exploration
Office of Minerals Mobilization

State Agencies:

Arkansas Geological and Conservation Commission
California Department of Natural Resources, Division of Mines
Colorado State Metal Mining Fund Board
Connecticut Geological and Natural History Survey
Commission of Public Lands, Hawaii
State Geological Survey of Kansas, University of Kansas
Kentucky Geological Survey, University of Kentucky
Massachusetts Department of Public Works
Department of Conservation, Geological Survey Division, State of Michigan
New Hampshire State Planning and Development Commission
Nevada Bureau of Mines, University of Nevada
North Carolina Department of Conservation and Development
Bureau of Topographic and Geologic Survey, Department of Internal Affairs, Commonwealth of Pennsylvania
State of Rhode Island and Providence Plantations
Washington Department of Conservation, Division of Mines and Geology
Wisconsin Geological and Natural History Survey, University of Wisconsin
Geological Survey of Wyoming

Commonwealth:

Puerto Rico Economic Development Administration

In addition to the agencies named above, the Geologic Division has cooperated from time to time with other organizations, and some of the results described in the following pages stem from work supported in previous years by agencies not listed above. All cooperating agencies are identified where appropriate in the individual papers of chapter B, and they are mentioned in connection with some of the larger programs in chapter A. Space limitations make it impossible to identify their contributions in connection with many of the short statements in the following pages but it is a pleasure to acknowledge here the financial support and splendid technical cooperation we have received from all of them.

Nearly everyone in the Geologic Division contributed directly or indirectly to this report, which was prepared between March and June 1960, but the chief responsibilities for it were held as follows: V. E. McKelvey planned and directed all phases of the preparation of the report, and assembled chapter A from information supplied by many project chiefs and program leaders. R. A. Weeks and R. L. Boardman compiled the list of investigations in progress, and David Gallagher compiled the list of publications and the index to chapter B. Doris I. Kniffin managed the clerical aspects of the project. J. P. Albers and A. B. Griggs helped process the papers of chapter B, and F. C. Calkins critically reviewed nearly all of both chapters and vastly improved their style and expression. I am deeply grateful to these people and to the members of the Division as a whole for their enthusiastic support of this undertaking.

Charles A. Anderson

CHARLES A. ANDERSON,
Chief Geologist.

Synopsis of Geologic Results

Prepared by members of the Geologic Division under the direction of V. E. McKelvey

GEOLOGICAL SURVEY RESEARCH 1960

GEOLOGICAL SURVEY PROFESSIONAL PAPER 400-A

A summary of important results recently obtained, accompanied by a list of reports released in fiscal 1960, and a list of investigations in progress

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1960

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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MINERAL RESOURCE INVESTIGATIONS

Most of the investigations of mineral resources (including fuels) made by the Geological Survey can be grouped into (a) district and regional studies and (b) commodity and topical studies. The district and regional studies are focused on areas known or thought to contain mineral resources; their purpose is to establish guides useful in the search for concealed deposits, define areas favorable for exploration, and appraise known and potential resources. Most studies of this kind involve geologic mapping and many of them ultimately help to develop general principles of wide application. The commodity and topical studies deal with the appraisal of national resources of various minerals, synthesis of empirical data on ore habits that help to define environments favorable for the occurrence of useful minerals, and experimental and theoretical studies of the origin and distribution of such minerals. The long-range aims of both groups of studies are to obtain data on field relations and on theoretical principles that will provide a foundation from which private industry can extend its search for usable raw materials and that will provide the nation as a whole with a continuing appraisal of its mineral wealth.

Important new findings in the fields of heavy metals, light metals and industrial minerals, radioactive minerals, and fuels are summarized in the following pages.

HEAVY METALS

DISTRICT AND REGIONAL STUDIES

Michigan iron districts

Geologic mapping and magnetic surveying of the Michigan iron districts, in cooperation with the Michigan Geological Survey Division, have established in considerable detail the distribution of iron-formations of several areas, notably the Iron River-Crystal Falls district (James and others, 1960) and the adjoining Lake Mary quadrangle (Bayley, 1959a); in the latter area, the work contributed to the discovery of a Precambrian iron-formation, about 200 feet thick, in secs. 24 and 25, T. 43 N., R. 31 W., Iron County, and sec. 30, T. 43 N., R. 30 W, Dickinson County. The formation is concealed by Pleistocene deposits and has now been explored by drilling.

Sedimentary iron ore in the Christmas area, Arizona

A deposit of sedimentary iron ore has been discovered in the Christmas quadrangle, Arizona by Willden (Art. 11[1]). It is in a bed 5 to 7 feet thick near the top of the Martin formation, of Devonian age. As it contains only about 37 percent iron, it probably is not minable now, but the occurrence suggests that other sedimentary iron deposits may be found in rocks of this age in Arizona.

Manganiferous zone of the Butte district, Montana

As a part of a regional study of the Boulder batholith, Montana, Smedes (Art. 12) has found that more than 6,000 feet of volcanic rocks lie uncomformably on the batholith and older rocks. Block faulting occurred repeatedly, at one time producing a graben west of Butte. Gravity surveys by W. T. Kinoshita indicate that the floor of this graben lies at a depth of about 1,000 feet beneath welded tuff, and Smedes believes that quartz monzonite beneath the floor may contain unexplored, truncated segments of metalliferous quartz veins of the manganiferous zone of the Butte district.

Manganese deposits near Philipsburg, Montana

Deposits of oxidized rhodochrosite near Philipsburg have been the only consistent source of battery-grade manganese ore in the United States. Detailed study by W. J. Prinz has shown that the primary rhodochrosite replacement deposits contain abundant zinc in the southern part of the district, but none in the northern part. They consist of both bedding replacements at bed-vein intersections, and of near-vertical pipes that swell in favorable host beds. The depth of oxidation of the primary deposits is shallow where the host rock consists of impure limestone, and deep where the host rock is marble.

[1] Article 11 in Professional Paper 400-B. Similar references to papers in chapter B are given in the same style.

Michigan copper district

The Michigan copper district has been studied by many geologists for more than a century, and its major geologic features are well known, but recent intensified study of certain aspects of its geologic setting has yielded results useful in looking for new deposits. R. E. Stoiber and E. S. Davidson (1959), for example, have shown that the major copper deposits occur in a relatively restricted zone that is roughly defined by the regional distribution of the minerals contained in the amygdules of basalts. White (1960a) has discussed evidence that copper at the base of the Nonesuch shale (White Pine mine) extends over a wide area and that it was deposited mostly if not entirely before the shale was deformed. The search for new deposits, therefore, need not be confined to areas near major faults, as might have been inferred from prior studies, and it has in fact been profitably extended, during the last few years, into areas that were formerly overlooked or considered unfavorable.

Pima copper district, Arizona

In the Twin Buttes quadrangle, Arizona, clues to the location of concealed copper ore bodies have been found by Cooper (1960) in a study of the geologic setting of the Pima mining district. Two orogenic episodes followed the deposition of the Cretaceous rocks that underlie part of the district, one earlier than the ore and the other later. The earlier episode resulted in complex folds and faults that trend northwest; the other resulted in the rotation of a large ill-defined structural block around an axis trending northeast, and also involved thrust faulting on a large scale. From the geologic relations indicated by the field data, Cooper estimates that the thrust plate moved about 6½ miles to the north-northwest. If this estimate is correct, the roots of several major ore bodies are in part of the district that has not yet been explored.

Upper Mississippi Valley zinc-lead district

Long range geologic studies of the upper Mississippi Valley lead-zinc district, in part in cooperation with the Wisconsin Geological and Natural History Survey and the Iowa Geological Survey, have recently culminated in a report by Heyl and others (1960) that describes structural and stratigraphic controls useful in prospecting. The principal structural features in this district are three first-order anticlines that trend westerly; their north limbs dip more steeply than their south limbs and reverse faults occur locally along the north limbs. The associated folds decrease in abundance and magnitude northward. Minor reverse and bedding-plane faults associated with second- and third-order folds, whose trends form a rhombic pattern, control the location of most zinc ore bodies. The lead ore deposits, many of which were formerly important, are controlled either by a group of joints resulting from tension, or a pair resulting from shear. Studies made by J. W. Allingham, J. E. Carlson, Harry Klemic, T. E. Mullens, and J. W. Whitlow after completion of Professional Paper 309 indicate that many of the second- and third-order folds and associated faults are probably the result, rather than the cause, of the emplacement of the ore bodies; i.e. they formed by compaction and subsidence in areas where mineralizing fluids dissolved limestone. This interpretation does not invalidate the prospecting techniques outlined in the professional paper, but it sets rough limits to the areas in which ores of lead and zinc are likely to be found.

East Tintic silver-lead district, Utah

On the basis of published results of a long-range study by Lovering, Morris, and others in the East Tintic district, Utah, the Bear Creek Mining Company has recently made important new discoveries of ore. Large, high-grade silver-lead replacement ore bodies there are found in places where steep north-northeasterly fissures cut west-dipping thrust faults that involve sedimentary rocks of early Paleozoic age. The sedimentary rocks are largely overlain by lavas, which were altered by hydrothermal solutions but which do not contain ore bodies. In an effort to aid in the search for concealed ore bodies of the East Tintic type, Lovering and his co-workers (1960) made detailed studies to establish the relations between the hydrothermally altered zones in the lavas and known ore bodies in the underlying sedimentary rocks. During the course of this study they also found primary geochemical anomalies in the altered rocks up-rake from ore-localizing structures. In order to test the validity of the techniques developed, a hole was drilled in an area that showed the same type of late stage alteration as that over the known Tintic Standard ore body and that also contained an encouraging geochemical anomaly. This hole penetrated low-grade ore; and, what was even more important, it cut rocks much younger than were expected at this depth. An analysis of the general geologic structure of the East Tintic Mountains, and of the detailed structure of the East Tintic district, led to the conclusion that a concealed west-dipping thrust fault lay between the drill hole and old mine workings about 1,400 feet to the west. The occurrence even of low-grade ore near a large unprospected fault, in an area that showed favorable late-stage altered zones and a geochemical anomaly at the surface, strongly indicated the presence nearby of a concealed ore center. The Bear Creek Mining Company therefore sunk the Burgin exploration shaft and drove west on the 1050 level. They found the thrust fault near its expected position, and by further exploration found three ore zones, one of which may be comparable in size and grade to the largest previously known ore deposit in the district. This discovery has opened entirely new ground to exploration, and has aroused interest in the techniques developed, which should be applicable elsewhere.

Coeur d'Alene lead-zinc-silver district, Idaho

In the Coeur d'Alene district S. W. Hobbs, A. B. Griggs, R. E. Wallace, and A. B. Campbell have amassed evidence that confirms major post-ore strike slip on the Osburn fault, which extends across the district (see Wallace and others, Art. 13), and the alinement of the major ore bodies along a series of well-defined zones or belts. With these interpretations as guides, it should be possible to concentrate future exploration on the most promising areas. From studies of the mineralogy of the Coeur d'Alene district V. C. Fryklund (Art. 15) has concluded that three different sources may have contributed to the main period of mineralization. R. G. Coleman, R. G. Arnold, and V. C. Fryklund, in a study of ores from the Highland Surprise mine in the Coeur d'Alene district, have shown that the estimated temperature of formation ranged from 370° to 492° C for pyrrhotite in 62 samples, and from 375° and 490° for sphalerite coexisting with pyrrhotite in 14 samples. There appears to be no systematic relation between depth and temperature, although the samples represent a vertical range of 1,600 feet.

The Colorado mineral belt

Nearly all of the major mining districts of Colorado are in the narrow so-called "Colorado mineral belt," which extends southwestward from central Colorado to the San Juan Mountains. This belt is characterized by intrusive porphyries and associated ore deposits of Laramide age. Tweto and Sims (Art. 4) have found evidence that it extends along an ancient zone of weakness defined by northeast-trending shear zones of Precambrian age. Intermittent movement took place in this zone from early in the Precambrian to the Tertiary, and during Laramide time magmatic activity occurred throughout its length. Tweto (Art. 5) has also found that most of the faults that appear to displace ore bodies in the Leadville district were actually in existence when porphyries of several varieties were emplaced. As the porphyries are pre-ore, the faults are also pre-ore, although post-ore movement has occurred on many of them.

Base and precious metal deposits in north-central Nevada

An analysis of the regional structure and distribution of ores in north-central Nevada by Roberts (Art. 9) indicates that many of the mining districts occur within northwest-trending zones of structural weakness. Doming along these zones has formed belts of windows in the upper plate of the Roberts Mountain thrust, which expose favorable carbonate host rocks in the lower plate. Carbonate rocks in the lower part of the sequence—for example, the Eldorado and Hamburg dolomites—may contain lead-zinc-silver deposits in favorable structural settings, such as fault intersections. The more siliceous rocks in the upper plate close to the thrust may contain minable bodies of gold ore and barite, especially near intrusives.

Rhenium and molybdenum in the Runge mine, South Dakota

In the Runge mine, South Dakota, water-soluble rhenium and molybdenum have been found during routine spectrographic analysis in a sandstone-type uranium-vanadium deposit (Myers and others, Art. 20). Six of the 27 samples analyzed contained 30 to 700 ppm rhenium and 24 contained 3 to 3,000 ppm molybdenum. Much of the rhenium is water soluble, and its concentration in residues obtained by leaching samples with distilled water and then evaporating is 10 to 25 times greater than the concentration in the samples themselves. The water-soluble rhenium and molybdenum are most abundant in the oxidized and partly oxidized ore that contains paramontroseite, nearly amorphous uraninite, häggite, and minor carnotite. This ore is found only in the upper part of the deposit and along fractures that cut sandstone containing uraninite, coffinite, and montroseite, and it probably makes up less than 10 percent, by volume, of the deposit.

Other districts in Western United States

During regional studies of the Idaho batholith, B. F. Leonard has found that wide parts of the Johnson Creek-Quartz Creek silicified zone are favorable sites for tungsten and gold mineralization.

In the northern Cascades of Washington, F. W. Cater has observed that the important ore deposits are restricted to northwest-trending shears in the Cloudy Pass batholith, to breccias related to it, and to replacement zones in the gneisses peripheral to it. The area may contain undiscovered ore deposits in similar relations to other batholiths. In the Loon Lake area of northern Washington A. B. Campbell has found that many of the lead-zinc, copper, talc, and barite deposits are related spatially to a northeasterly trending zone of faults and dikes.

Mineralogic studies of samples from a prospect in the Lone Mountain area, near Tonapah, Nevada, show that it contains manganoan hedenbergite, andradite, zincian nontronite, sphalerite, galena, magnetite and calcite (Gulbrandsen and Gielow, Art. 10)—a mineral assemblage characteristic of a number of pyrometasomatic deposits being mined elsewhere. The deposit from which these samples came apparently does not contain amounts of ore large enough to be minable, but the mineral assemblage suggests that minable deposits of this type may be found at Lone Mountain.

In the Rosita district of the West Mountains, Colorado, Q. D. Singewald and M. R. Brock have found that the location of major deposits of base and precious metals in the Tertiary volcanic rocks is controlled by northwest-trending faults in the underlying Precambrian crystalline rocks.

Metalliferous deposits in Alaska

Near Nome, Alaska, Hummel (Art. 17) has identified two structural systems in the bedrock. Lode and placer deposits of the Nome goldfields are closely associated with some of the folds and faults of the younger system. Concentrations of Cu, Zn, Bi, and Mo in the sediments of Thompson Creek in the Kigluaik Mountains are evidence that metalliferous lodes exist in a part of the area not formerly known to contain them (Hummel and Chapman, Art. 16).

Sainsbury and MacKevett (Art. 18) have studied quicksilver deposits in the southwestern part of Alaska and find that their localization is structurally controlled. The quicksilver is associated with antimony in these deposits, and is probably of Tertiary age. The mercury was deposited mainly as cinnabar in open fractures in competent rocks, but each deposit has important individual structural controls that affected ore deposition and may guide further exploration.

COMMODITY STUDIES

In the field of commodity studies, maps showing the distribution of known deposits of useful minerals in the United States have been prepared during the past year to record and analyze the distribution of mineral deposits. This is a first step toward the preparation of metallogenic maps that will relate the distribution of mineral deposits to tectonic and petrologic provinces and to tectonic history.

Also in the field of commodity studies, Heyl and Bozion (Art. 2) have investigated the distribution of oxidized zinc deposits in the United States. They find that most of them have directly replaced sulfide deposits, and that they showed a markedly varied pattern, dependent on (a) pH, rainfall, and climatic factors; and (b) wall rocks and geologic variations between metallogenic provinces.

For many elements in the United States, the tonnage of minable reserves in short tons has been found to be equal to crustal abundance of the element in percent (A) times 10^9 to 10^{10} (McKelvey, 1960). This relation is useful in forecasting reserves in large segments of the earth's crust. For estimating world reserves of many not yet actively sought elements, a figure of A x 10^{10} to 10^{11} will probably give the right order of magnitude.

TOPICAL STUDIES

A broad-scale attack on the origin and physicochemical characteristics of ore-depositing solutions in the Creede district, Colorado, is getting well under way. The geologic setting of the OH vein, a basemetal deposit selected for this study, has been studied in detail by Steven and Ratté (Art. 8), who have shown that the vein was deposited in a shallow volcanic environment adjacent to a large volcanic caldera. The ores are localized along faults in a complex graben that extends outward from the caldera; movement on these faults occurred many times while the caldera was subsiding, but mineralization did not take place until the last main period of fault movement. Several new tools and techniques have been developed by Edwin Roedder for study of fluid inclusions in the OH vein (see p. A73), and they have already yielded some preliminary results. For example, the absence of opaque specks within fluid inclusions seems to indicate that the ore was deposited from a solution that contained only small amounts of the ore metals, perhaps as little as 10 ppm (Roedder, 1959). Preliminary data obtained by E. Roedder, B. Ingram, and M. Toulmin from strongly zoned sphalerite crystals at Creede suggest that they were deposited from a rather concentrated brine, high in Na and Cl and lower in K, Ca, Mg, B, and SO_4, diluted at times to various degrees by ground water or water from other sources. The D/H isotope ratios in the inclusions determined by Wayne Hall and Irving Friedman are lower than those in sea water but higher than those in meteoric waters in similar environments.

Mackin and Ingerson (Art. 1) have proposed a "deuteric release" hypothesis for the origin of magmatic ore-forming fluids. The classical view is that metals not accepted in rock-forming minerals become concentrated in late-stage fluids, which may escape from the magma and deposit ores. According to the "deuteric release" theory, iron and other metals are incorporated in early-formed biotite and hornblende that crystallize at depth; if the magma was intruded only to a shallow depth, deuteric alteration could release the metals to the escaping interstitial fluid.

Chemical criteria for recognition of possible ore-depositing mineral waters of different types have been developed by White (Art. 206) through the study of existing waters.

D. F. Hewett and Michael Fleischer (1960) have studied the mineralogy of more than 250 specimens of manganese oxide minerals collected throughout the United States and interpreted their origin. Of the 27 manganese oxide minerals identified, one group of 10 is persistently supergene; another group of 9 is persistently hypogene and a third group of 8 includes those that are supergene in some places and hypogene in others. Hewett has also found that minor amounts of several metals, alkalies, and alkaline earths are present in the oxides of one mode of origin and absent in others. Tungsten nearly always occurs in hydrothermal vein oxides and in those deposited in the aprons of hot springs, but it is sporadic and very low or absent in the supergene oxides. Most of the minor elements in the supergene oxides are those known to exist in the unweathered minerals from which the oxides were derived.

Fleischer (1959, 1960a) has reviewed the geochemistry of rhenium, with special reference to its occurrence in molybdenite. Rhenium is most abundant in porphyry copper ores, but the factors controlling its concentration are not yet understood.

LIGHT METALS AND INDUSTRIAL MINERALS

DISTRICT AND REGIONAL STUDIES

Mount Wheeler beryllium deposit, Nevada

Stager (Art. 33) has studied a new association of beryllium that has been found in the Mount Wheeler mine, Nevada, where phenacite, bertrandite, and beryl, intimately associated with scheelite and fluorite, replace the lowest limestone bed along vertical quartz veins in the Pioche shale of Cambrian age. The beryllium minerals probably were deposited by hydrothermal solutions originating in a nearby granitic intrusion, and it seems likely that similar deposits of these easily overlooked beryllium minerals may be found in the surrounding area.

Beryllium in the Lake George district, Colorado

In the Lake George district, Colorado, Sharp and Hawley (Art. 35) have recognized bertrandite-bearing greisen as a new type of beryllium ore. Similar greisen may exist elsewhere unrecognized, as the beryllium silicate, bertrandite, is difficult to distinguish from feldspar. The Lake George district is crossed by pre-mineralization lineaments that at least locally contain greisen with small amounts of bertrandite (Hawley and others, Art. 34).

Beryllium in tin districts of the Seward Peninsula, Alaska

A review of all available geologic information has shown that the tin districts of the Seward Peninsula, Alaska, contain promising amounts of beryllium. Beryllium was identified originally in 1940 by George Steiger in samples collected by J. B. Mertie, Jr., and R. R. Coats, from bedrock sources at the Lost River tin mine, and at the Ear Mountain and Cape Mountain tin areas. Spectrographic analyses by Shrock in 1943 of samples of banded tactite collected by A. Knopf from Tin Creek, about 2 miles from Lost River, showed beryllium in the range of 0.016–0.08 percent. Drill cores obtained by the Bureau of Mines at the Lost River mine in 1943–44 (U.S. Bureau of Mines Report of Investigations 3902) also contained detectable beryllium as beryl and phenacite, and Coats and P. L. Killeen identified beryl in surface veinlets in metasomatized marble at the Lost River mine. Steiger found that the idocrase in samples collected by Coats from the same region is consistently high in beryllium, and deeper holes drilled by the U.S. Tin Corporation in 1955 showed that parts of the underlying granite are abnormally rich in beryllium. Phenacite was found to be present in one core sample by C. L. Sainsbury.

Tin placer concentrates from DMEA projects at Cape Mountain and at Earl Mountain, which were analyzed spectroscopically by the U.S. Bureau of Mines, and tin placer concentrates from Bureau of Mines tin exploration near Earl Mountain and Cape Mountain (U.S. Bureau of Mines Report of Investigations 5493 and 7878) contain amounts of beryllium that are generally higher than samples of stream sediments from beryllium-rich provinces elsewhere in the United States. Additional detailed work may well outline deposits of economic importance at any or all of the above localities, as well as in other tin-rich areas for which information on beryllium is lacking at present.

Beryllium and fluorspar in the Thomas Range, Utah

In the spring of 1960, prospectors discovered an extensive and new type of beryllium deposit in the vicinity of Spors Mountain in the Thomas Range district, Juab County, Utah. This area has just been mapped by Staatz and Osterwald (1956) in connection with a study of its fluorspar and uranium deposits, so it is possible to make a preliminary interpretation of the geology of the beryllium deposits that may be helpful in their further exploration. The account here is based on that mapping, supplemented by a recent field examination by Staatz and W. R. Griffitts.

The beryllium deposits are in rhyolitic tuff on the lower slopes of Spors Mountain, where, because of its friable character, the tuff breaks down and is concealed by slope wash and younger deposits. The tuff is a part of a sequence of faulted and tilted Miocene volcanics, which is overlain by only slightly faulted and imperceptibly tilted Pliocene volcanics and Quaternary lake beds.

The only beryllium-bearing mineral thus far identified is bertrandite, found by E. J. Young and E. C. T. Chao by X-ray analysis. Other epigenetic minerals include opal, montmorillonite, fluorite, and calcite. Bertrandite and other replacement minerals are most abundant in elliptical nodules that range from 0.5 to at least 8 inches in length. Five samples of the tuff from two of the occurrences were determined by berylometer measurements to carry 0.25 to 1.5 percent BeO; nodules from these same tuffs contain 1.8 to 10.7 percent BeO respectively. The beryllium-rich layers, which are not everywhere at the same horizon in the tuff, may be several yards thick, but contain erratically distributed barren areas. The bertrandite, like the fluorspar, probably was deposited in Pliocene time during the waning stages of the younger period of volcanism.

Plate 1 of Bulletin 1069 by Staatz and Osterwald shows the general distribution of the volcanics (vt on the Plate 1 explanation) that contain the beryllium-bearing tuff, and exploration by mining companies has disclosed a number of localities, over an area of several square miles, where the bed is mineralized. Because of the extensive distribution of the favorable tuff and its repetition by faulting, which has brought it close to the surface at numerous places, opportunities for further discoveries are promising, and the reserves of beryllium in the area could be very large.

Black Hills pegmatites, South Dakota

In the southern Black Hills, pegmatites—which are mined for feldspar, mica, lithium minerals, and beryl—are in medium- to high-grade metamorphic rocks intruded by the so-called granite of Harney Peak. Detailed studies have helped to define areas favorable for prospecting and have led to increased knowledge of the structure, mineral zoning, and origin of the zoned pegmatites. The Hugo pegmatite, for example, near Keystone, has been found by Norton (Art. 32) to consist of seven zones and two replacement bodies. Most of it crystallized from a magma that became increasingly silicic as crystallization proceeded; the core and the replacement bodies, however, which are rich in alumina and the alkalies, were probably deposited from a water-rich fluid that separated from the silicate rest liquid. In the Fourmile quadrangle J. A. Redden has found that the zoned pegmatites occur in metamorphic rocks several miles from any large body of granite. The high temperatures that prevailed in and near the major intrusive bodies favored the formation of numerous unzoned quartz-feldspar pegmatites, but not the larger and more valuable zoned pegmatites.

Talc and asbestos deposits

From a study of the petrology and geochemistry of certain talc-bearing ultramafic rocks and adjacent country rocks in Vermont, A. H. Chidester has concluded that the talc was formed by regional metamorphism unrelated to serpentinization (see p. A67). A. F. Shride has shown that the principal asbestos-producing areas of east-central Arizona are in a structural setting typical of the Colorado Plateau province, rather than of the Basin and Range province as previously thought, and that the geologic structures and extensive bodies of intrusive diabase which favored the formation of asbestos are of Precambrian rather than post-Paleozoic age.

Phosphate deposits in Montana and Wyoming

The phosphate resources of parts of Montana and Wyoming have recently been estimated as a part of a long range study of the distribution, resources, and origin of the Permian Phosphoria formation. In southwestern Montana and a small part of adjacent Idaho, Swanson (Art. 31) estimated that the phosphatic shales contain 450 million tons of phosphate rock in units that are more than 3 feet thick and that average more than 31 percent P_2O_5; and 6 billion tons averaging more than 24 percent P_2O_5. Corresponding contents of uranium in the two grade categories are 35,000 and 420,000 tons. The same rocks also contain 2.5 to 3 percent fluorine. These shales also contain more than 2.2 billion tons of rock in units that are more than 3 feet thick and that average more than 18 percent P_2O_5.

R. P. Sheldon estimates that the phosphatic shales in Wyoming and a small part of eastern Idaho contain 1.4 billion tons of phosphate rock in units more than 3 feet thick and averaging more than 31 percent P_2O_5; 6.5 billion tons containing more than 24 percent P_2O_5; and 19 billion tons containing more than 18 percent P_2O_5. He also estimates that the phosphatic shales contain 5.5 billion tons of phosphate rock averaging more than 0.010 percent uranium and 13.5 billion tons averaging more than 0.005 percent uranium.

Phosphate in northern Florida and South Carolina

In the northern part of the Florida Peninsula, reconnaissance by G. E. Espenshade and Charles Spencer indicate that phosphatic dolomite and phosphorite are widespread in the Miocene Hawthorne formation. The apatite is locally altered to aluminum phosphate, as in the Land Pebble field farther south. In the Charleston, South Carolina area, Malde (1955a) has shown that phosphate nodules in the upper part of the Oligocene Cooper marl were formed by replacement of calcium carbonate and were later reworked to form the basal part of the Pleistocene Ladson formation.

High calcium limestone in southeastern Alaska

The Heceta-Tuxekan Islands area, southeastern Alaska, contains a thick sequence of relatively pure Silurian limestone, associated with marine high-rank graywacke. Chemical analyses of 56 composite samples of the limestone collected by G. D. Eberlein over a stratigraphic interval of 8,800 feet indicate that most of it contains more than 90 percent of $CaCO_3$, and less than 1 percent of MgO, 0.8 percent of R_2O_3, 0.1 percent of combined alkalies, 0.2 percent of total S, 0.02 percent P_2O_5 and 5 percent acid insolubles (mostly SiO_2). In samples from a zone approximately 1,000 feet thick near the middle of the sequence, the rock is nearly pure calcite, suitable for metallurgical uses.

Clay deposits in Maryland

In a cooperative investigation with the Maryland Department of Geology and the U.S. Bureau of Mines, M. M. Knechtel, J. W. Hosterman, and H. P. Hamlin have found that much nonmarine clay of Cretaceous age in Maryland is suitable for fire clay. They have also found that large deposits of marine "bloating" clay of Tertiary age appear to constitute excellent raw material for the manufacture of light-weight concrete aggregate (Knechtel, Hosterman, and Hamlin, 1959; see also Art. 29). Thick deposits of this clay underlie extensive areas that include many potential strip-mining sites.

Clay deposits in Kentucky

A cooperative study, with the Kentucky Geological Survey, has shown that the valuable deposits of flint clay in northeastern Kentucky were formed by subaqueous leaching of normal plastic clays in swamp deposits of Early Pennsylvanian age, immediately above an erosion surface cut on sedimentary rocks of Mississippian age (Huddle and Patterson, 1959; Patterson and Hosterman, 1960). The Lee formation, which contains the clay beds, grades laterally from very clean quartz sandstone into muddy sandstone, siltstone, shale, and claystone.

Green River saline deposits, Wyoming

During the course of a long-range study of the stratigraphy, mineralogy and origin of the Green River formation, which contains vast reserves of trona ($3Na_2O \cdot 4CO_2 \cdot 5H_2O$), Milton and others (1959, 1960) have recently summarized information on the mineral assemblages present in these remarkable deposits. Carbonates, of which the trona is one, not only make up the bulk of the chemically precipitated minerals, but are present in great variety also—in fact, the Green River contains about one-fourth of all known species of carbonates. The beds also contain 12 species of silicate minerals, including authigenic amphibole magnesioriebeckite, the pyroxene acmite, and the boron plagioclase reedmergnerite.

Carlsbad potash district, New Mexico

Field studies of the Carlsbad potash deposits by C. L. Jones, H. C. Rainey, and B. M. Madsen have developed the concept that late-stage solutions effected widespread metasomatic replacement in localized parts of favorable beds of previously precipitated salts (Jones, 1959). These solutions introduced K, Mg, and SO_4 and removed Na, Ca, and Cl or precipitated them elsewhere. There is evidence that the late-stage replacement was structurally controlled.

Borate deposits of southwestern United States

Studies of the borate deposits of the Mojave Desert and adjacent parts of California and western Nevada continue to yield new information about their mineralogy, origin, geologic setting, and resources. R. C. Erd has shown that the Kramer district contains a unique assemblage of nearly 50 minerals; the list now includes 18 species found there during his study. Among them are four black ferromagnetic iron sulfides, some locally abundant, which have x-ray powder patterns distinct from those of previously known iron sulfides. Erd has also shown that at Kramer layers of pyroclastic material have been altered to analcime, clinoptilolite, phillipsite, searlesite, and authigenic adularia and albite. Samples from 10 playas in California and Nevada provided new occurrences of burkeite ($Na_6(CO_3)(SO_4)_2$) and searlesite, and one contained an unidentified hydrous sodium calcium sulfate. Three rare borate minerals, hydroboracite, inderite, and kurnakovite, were found in the Eagle Borax deposit in Death Valley.

During examination of the Kramer ore body, W. C. Smith found evidence that underground solution has removed much borax, particularly along faults. Peculiar features of the ore body, now believed to be effects of solution, include its abrupt, blunt edges, certain valley-like depressions in the top of the ore, and a hanging wall which in places consists of slumped insoluble residue containing secondary magnesium and calcium borates

An improved understanding of the geologic history of Searles Lake, and of the probable source of its boron, has resulted from G. I. Smith's study of regional as well as local evidence. The study confirms Gale's general picture of Searles Lake basin as the third in a chain of basins that received water from the Owens River during the wet periods of the Pleistocene and that partially or totally dried up during ensuing dry periods. Drill cores from the basins (see U.S. Geological Survey Bulletins 1045–A and 1045–E) show that Searles Lake was an evaporating pan intermittently throughout much of Quaternary time, yet only during the last two major dry periods and only in Searles Lake basin did desiccation produce salt layers that are commercially valuable by present standards. From the interstitial brines in these upper salts at Searles Lake commercial plants recover sodium, potassium, lithium, carbonate, sulfate, phosphate, and bromine, as well as borate products. Smith concludes that although Searles Lake had a long history as an evaporating pan, boron and other valuable constituents were present in the Owens River system only after their introduction about 50,000 to 60,000 years ago by an episode of volcanic and hot spring activity in the Owens River drainage. Because Searles Lake ceased overflowing about the same time, it concentrated most of the valuable elements subsequently brought to it by the Owens River.

COMMODITY AND TOPICAL STUDIES

Beryllium

The supply of beryllium obtained from pegmatites throughout the world is so small that hope for any great increase in production rests mainly on the possibility of finding major beryllium deposits in nonpegmatitic rocks. Available data on the distribution of beryllium in rocks show that certain types of quartz-gold and quartz-tungsten veins, certain manganese veins, tactites, and some other varieties of rock warrant further investigation (Warner and others, 1959, and Norton and others, 1958 [2]). The recent discoveries already mentioned (see p. A5) encourage the belief that minable nonpegmatitic deposits can be found. Griffitts and Oda (Art. 44) have found that the beryllium content of soils and alluvium can be used in geochemical prospecting for beryllium deposits. Development of beryllium detectors, based on the gamma-neutron reaction, has contributed to beryllium exploration by providing a rapid means of analysis (Vaughn and others, 1960).

[2] Norton, J. J., Griffitts, W. R., and Wilmarth, V. R., 1958, Geology and resources of beryllium in the U.S.: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, 2d, Geneva, 1958, Proc., v. 2, p. 21–34.

Selenium

A study of the geology and geochemistry of selenium indicates that this element is markedly concentrated in epithermal antimony and silver deposits (Davidson, 1960). In volcanic rocks, it is concentrated in ash and in rocks composed of ash, rather than in flow rocks (Davidson and Powers, 1959). Selenium has also been found in low grade concentrations in some phosphorites and black shales of the Permian Phosphoria formation and higher grade concentrations are associated with sandstone-type uranium deposits and some large sulfide deposits.

Marine phosphorites

Continued studies of the phosphorites in the Permian Phosphoria formation show that they are part of an assemblage of lithofacies that formed synchronously along the western edge of a shoaling land mass of low relief. The lateral sequence of facies, in a shoalward direction, is typically (a) carbonaceous mudstone, (b) phosphorite, (c) chert, (d) light colored carbonate rock and sandstone, (e) saline rocks, (f) greenish-gray mudstone, and (g) red beds (McKelvey and others, 1959). This sequence is reproduced, in whole or part, in both the same order and reverse order in vertical sections, where the facies intertongue as the result of the lateral shifting of environments with transgressions and regressions of the sea. Petrographic studies by R. A. Gulbrandsen, E. R. Cressman, R. P. Sheldon, and T. M. Cheney indicate that much of the phosphorite was formed by direct precipitation from sea water or interstitial water. The lateral sequence of chemical sediments suggests that a salinity gradient existed in the Phosphoria sea, and Gulbrandsen has shown that the succession of chemical sediments might have resulted from phase precipitation in a shoalward moving current.

Information on the origin of the phosphorite assemblage of sediments, gained as the result of the observations of previous workers (notably Kazakov and Brongersma-Sanders) as well as by studies of the distribution of ancient and modern sediments, provides clues helpful in the search for oil as well as phosphorite (McKelvey, 1959). Phosphorites in the modern ocean form where cold waters rich in P, N, and Si upwell. These waters become saturated with phosphates as the temperature rises with decreasing depth, and they may also become successively saturated with carbonates and saline minerals as they move shoreward. The exceptionally rich nutrient content of these waters support lush growths of organisms, which produce important accumulations of carbonaceous matter in the sediments. Sulfides and petroleum form under the reducing conditions that prevail where large amounts of carbonaceous matter are deposited; the petroleum often accumulates in stratigraphic traps that result from synchronous deposition of both reservoir beds and sealing beds in other parts of the same environment.

These relations indicate the following guides to the search for phosphorite and oil: (a) both phosphorite and oil are likely to occur in lateral or vertical association with bedded chert, black shale, and marine evaporites; (b) accumulations of oil are likely to occur in stratigraphic traps (such as carbonate rocks sealed by black shale, red beds, or evaporites) whose location can be predicted from the lateral and vertical sequence of lithofacies characteristic of this environment; and (c) as the main ocean currents and continental margins have not shifted much since the Cretaceous, upwelling occurred during the deposition of coastal plain formations in many of the same general areas in which it is occurring now. Coastal-plain sediments adjacent to areas of modern upwelling, then, are favorable for the occurrence of both phosphorite and oil.

RADIOACTIVE MINERALS

DISTRICT AND REGIONAL STUDIES

Colorado Plateau

A compilation of some twenty reports recently published on the geochemistry and mineralogy of the Colorado Plateau ores (Garrels and Larsen, 1959) documents two important conclusions: (a) the ores that occur in rocks saturated with water consist of low-valent minerals (chiefly vanadium clays, uraninite, coffinite, and montroesite), but those in unsaturated rocks consist partly or wholly of higher valent minerals, such as carnotite; and (b) the ore minerals in the unsaturated rocks were emplaced in a reducing environment, in Late Cretaceous or early Tertiary time, before regional deformation or during its early stages, so that movement of the transporting fluids was chiefly controlled by sedimentary structures in virtually undeformed rocks. These conclusions, resulting from years of work by many people both in government and in private industry, provide a sound basis for prospecting for uranium ores, not only on the Colorado Plateau, but in many other areas.

In the Slick Rock district, Colorado, Archbold (1959) has found that carbonate-rich zones in sandstone of the Salt Wash member of the Morrison formation are associated with ore deposits, and therefore can serve as guides to ore.

On evidence derived mainly from the relations between ores and penecontemporaneous structures, R. H. Moench and J. S. Schlee have concluded that the uranium deposits of the Laguna district in New Mexico were probably deposited under near-surface conditions prior to deep burial and regional tilting. The paragenesis of uranium ores in the Todilto limestone near Grants, N. Mex., indicates that the limestone is locally replaced by minerals of uranium, vanadium, and to a lesser extent by minerals of fluorine, iron, lead, manganese, molybdenum, and selenium (Truesdell and Weeks, 1959). Colloform uraninite formed after the early recrystallized calcite, pyrite, fluorite, montroseite, häggite, and vanadium clay; it was accompanied or closely followed by coffinite, galena, and calcite, and was followed by late calcite, pyrite, marcasite, häggite, and hematite.

Pitchblende has been identified as a secondary mineral in the Ambrosia Lake district, New Mexico (Granger, Art. 26) where it probably was deposited from ground water that dissolved uranium from oxidizing coffinite. Studies by I. A. Breger indicate that the carbonaceous substances coating the sand grains in the Ambrosia Lake ore are humic substances derived by alkaline extraction of low-rank coalified woody debris, and that they are not related to petroleum.

Gila County, Arizona

In Gila County, Arizona, uranium deposits occur in a potassic siltstone of the Precambrian Apache group. The uranium was probably derived from nearby intrusive diabase of about the same age (Neuerburg and Granger, 1960). Differentiation of the diabase magma, involving extensive reactions with aqueous fluids, resulted in ordinary diabase, diabase pegmatite, deuterically altered diabase enriched in potassium, syenite, aplite, and deuteric veinlets. The deuteric veinlets were deposited in contraction fractures by rest fluids as they drained from the magma. The distribution of uranium and copper in the differentiates indicates that these fluids removed most of the uranium, but little of the copper, that was originally contained in the magma.

Crooks Gap area, Wyoming

In the Crooks Gap area, Fremont County, Wyoming, J. G. Stephens found that the uranium is mainly in conglomeratic arkose beds of the Wasatch formation (Eocene?). Analyses of springs and seeps in the area show that water from Miocene tuffaceous rocks contains several times as much uranium as water from Eocene rocks, which suggests that the Miocene rocks may have been the source of the uranium.

Baggs area, Wyoming

In the Poison basin in the Baggs area of Wyoming, G. E. Prichard has recognized secondary ore minerals in an oxidized zone 20 to 70 feet below the surface in the Browns Park formation of Miocene(?) age; underlying tabular bodies of unoxidized ore appear to be parallel to the base of the zone of oxidation.

Gas Hills district, Wyoming

Most of the important deposits in the Gas Hills district, Wyoming, studied by H. D. Zeller, P. E. Soister, and D. L. Norton, are in coarse-grained arkosic sandstones of the upper part of the Wind River formation. Unoxidized uranium ores are enriched in molybdenum, arsenic, and selenium. R. C. Coleman has found that the mineral associations are largely controlled by the oxidation state of the ore zones. Uraninite, coffinite, iron sulfides, jorisite(?), calcium carbonates and sulfates are the minerals in the dark unoxidized ores. Uranyl carbonates and hydroxides form in the early stage of oxidation and are accompanied by the blue molybdenum bloom ilsemannite. The change from U(IV) to U(VI) compounds takes place much earlier than the oxidation of iron sulfides. As the iron sulfides begin to oxidize, the uranyl carbonates dissolve in the acid solutions and the uranyl ions then form complex ions with $(PO_4)^{-3}$ or $(AsO_4)^{-3}$ to produce more stable oxidation products. Some secondary enrichment takes place in sulfide rich zones, where uranium is reprecipitated by reduction. Geochemical evidence suggests that the metals in these deposits were leached from tuffs and arkose by alkaline solutions that accumulated in the Wind River basin. The fluids became progressively enriched in U, Mo, Se, As, and P by evaporation, dissolution, or base exchange. When the basin was tilted, the ore fluids moved into zones where H_2S had accumulated, and the ore metals were precipitated by reduction.

Black Hills, South Dakota

G. B. Gott and associates have found evidence in the southern Black Hills to indicate that carbonate-rich uranium-bearing water migrated vertically through breccia pipes and possibly fault zones, and laterally through permeable channel sandstones. Geochemical control of uranium deposition appears to have consisted principally of acidification and reduction of uranium-bearing solutions. This has been accomplished in at least one place by the intermingling of uranium-bearing bicarbonate solutions with sulfate waters derived from highly carbonaceous pyritic siltstone. In the northern edge of the Black Hills, R. E. Davis and G. A. Izett found that ore deposition was chiefly controlled by composition of the host rock and its geochemical environment, along with sedimentary structures; tectonic control in less important in this area than previously supposed.

Palangana salt dome, Texas

Weeks and Eargle (Art. 24) determined that the uranium deposit at Palangana salt dome is in Pliocene and Miocene sands at a depth of about 325 feet. They believe that the uranium was leached by alkaline carbonate ground water from tuffaceous sediments up dip, and was precipitated by reduction with H_2S emanating from the sulfurous caprock of the salt dome.

Uraniferous phosphorite in Eocene rocks, Wyoming

Although small quantities of phosphate, mostly in the mineral bradleyite ($Na_3Mg(PO_4)CO_3$), have been known to occur in the Eocene Green River formation and similar deposits, calcium phosphate deposits have been unknown in saline-bearing lacustrine rocks. Recently, however, Love and Milton (1959) found some thin apatite-bearing layers of dolomitic siltstone and oil shale intertonguing with trona-bearing beds in the Green River formation near Green River, Wyo. Selected samples contain, on the average, 0.05 percent uranium and 6.5 percent P_2O_5. Similar uraniferous phosphatic strata were found in the Lysite Mountain area in lacustrine tuffaceous siltstone in the Eocene Tepee Trail formation. As the known phosphatic beds are only a few inches thick, they are not minable, but their discovery opens up the possibility that thicker uraniferous phosphorites may be found in these or similar lacustrine deposits.

Uraniferous lignite in the Williston basin, Montana and North Dakota

In the Williston basin of Montana and North Dakota, N. M. Denson, J. R. Gill, and W. A. Chisholm have found that present-day ground waters from Oligocene and Miocene tuffs contain more uranium than those from other rocks, and they are also relatively high in V, SiO_2, Mo, Sr, As, and Se, which are all associated with the uranium deposits. From this evidence, they conclude that in the Williston basin, as in many other areas, the uranium in the lignite has been derived from the leaching of Oligocene and Miocene tuffs.

Chattanooga shale, Tennessee and Alabama

L. C. Conant and V. E. Swanson have described the geology, origin, trace elements, and organic material of the Chattanooga shale in central Tennessee and adjacent States. The Chattanooga is only about 35 feet thick in this area, but it has been divided into several units each fairly uniform in lithology and uranium content, that can be traced over thousands of square miles. The shale accumulated slowly in a shallow sea that gradually spread over an area of low relief, and it thins to extinction by overlap on older units in central Alabama and northeastern Mississippi, and also on the margins of the Hohenwald platform, a Devonian island in south-central Tennessee.

COMMODITY AND TOPICAL STUDIES

Distribution of epigenetic uranium deposits in the United States

Three maps on a scale of 1:5,000,000 have been published recently that show the relation of epigenetic uranium deposits to continental sedimentary rocks, to crystalline rocks older than Late Cretaceous, and to igneous rocks of Late Cretaceous and younger age (Finch and others, 1959). These maps provide a basis for analyzing the relation of the distribution of various types of deposits to the composition and age of the host rocks in which they were deposited, and they should help define areas and rocks favorable for prospecting.

Uranium in sandstone-type deposits

The previously mentioned investigation of the geochemistry and mineralogy of Colorado Plateau ores (Garrels and Larsen, 1959) has yielded many results of broad application. For example, Evans (1959) has defined the structure and fields of stability of the vanadium minerals in terms of Eh and pH. The trivalent oxide, montroseite, is converted by weathering to tetravalent and pentavalent minerals, but what species are formed depends on the Eh and pH prevailing in the environment. The primary tetravalent uranium minerals, which are almost insoluble under reducing conditions, also readily break down under oxidizing conditions (Garrels and Christ, 1959). Many of the higher-valent minerals formed on weathering are water-soluble and are deposited only through evaporation, but hexavalent uranium may be fixed in the zone of weathering if arsenic, phosphorus, or vanadium are available, because these elements form relatively insoluble compounds with uranium. Experimental determinations of the reducing effect of woody materials show that the amounts present in many rocks are adequate to reduce and precipitate uranium and vanadium brought to the environment in oxidized form (Garrels and Pommer, 1959).

Using radioactive daughter products as tracers, Rosholt (Art. 21) finds that it is possible to identify the process by which uranium migrates in sandstones and to estimate the time at which the migration took place.

Studies of some ore deposits in sandstone show that copper deposits are mainly in first-cycle arkosic sandstones, vanadium deposits are dominantly in second-cycle sandstones, and uranium deposits are either in first- or second-cycle sandstones (Fischer and Stewart, Art. 22). This distribution may be related to the geochemistry of these metals in the igneous environment. Much of the copper and uranium in igneous rocks and hydrothermal veins is in a readily oxidizable form, and thus available to circulate in first-cycle sediments. Vanadium in igneous rocks, on the other hand, is in a less available and less concentrated form, and forms clay minerals on weathering; diagenetic reactions and a second cycle of weathering may be required to mobilize it.

Uranium in petroleum

From an investigation of the association of uranium with petroleum and petroliferous rocks, K. G. Bell has concluded that petroleums do not contain significant quantities of uranium, and that petroleum does not act as ore-transporting fluids for uranium. He estimates that the average uranium content of crude oils is approximately one part per billion. Breger and Deul (1959) have also concluded that crude oil plays no part in the emplacement of uranium ore; they point out, however, that since migrating oil may pick up small quantities of uranium, the uranium content of oil may have some value as a guide to prospecting. This is partly confirmed by H. J. Hyden, who has found by experiments that crude oil can leach uranium from sandstone host rocks. Hyden also finds that the vanadium and nickel contents are related to the organic composition of the petroleum, but that the uranium content as well as the content of other metals is not.

Uranium in coal

The Geological Survey has recently published a group of ten reports (Bulletin 1055) that describe the occurrence of uranium in coal in northwestern South Dakota and adjacent areas in Montana and North Dakota, the Red Desert area of Wyoming, the Goose Creek and Fall Creek areas of Idaho, and the La Ventura Mesa area of New Mexico. The uranium content of the coal in these areas generally ranges from 0.003 to 0.1 percent, although in the Cave Hills area of South Dakota large tonnages average 0.7 percent. Most of the uranium-bearing coals are of low rank and contain more ash than nonuraniferous coals. The regional occurrence of uranium in coals that underlie Tertiary rocks containing volcanic materials, coupled with the fact that the uranium in individual coal beds generally increases toward fractures, permeable layers, or other structures that probably served as conduits for ground water, indicate that the uranium in these coals was deposited by circulating ground water that leached uranium from volcanic materials.

Several of the uranium-bearing lignites mentioned above were found by applying this theory to known information in the distribution of both coal and volcanic materials. In Bulletin 1055 Denson (1959) has used it also to indicate additional areas favorable for the occurrence of uraniferous lignite.

Uraniferous black shale and phosphorite

Investigations by V. E. Swanson of uranium in black shales show that uranium and distillable oil are quantitatively related in some shales, but not in others. The major factors controlling the oil yield and uranium content of these shales appear to be amount of organic matter, proportion of humic to sapropelic types of organic matter, the amount of phosphate, and depositional environment.

R. P. Sheldon (1959a, b) has found that phosphatic sediments of the Phosphoria formation deposited in an environment of low Eh are relatively rich in uranium, whereas those deposited in an environment of high Eh are relatively poor in uranium. He concludes that the low Eh of the depositional environment increases the concentration of uranium in apatite in one or both of two ways: (a) it converts uranium to the U^{+4} ion and thereby more U(IV) is substituted for calcium in the apatite lattice, or (b) the carbonaceous matter that accumulates in environments of low Eh inhibits the growth of apatite crystallites, allowing more U(VI) to be absorbed on crystallite surfaces.

Thorium in monazite

From the available thorium analyses of monazite, Overstreet (Art. 27) finds that monazite is rare in the greenschist facies, rare to sparse in the epidote-amphibolite facies, sparse to common in the amphibolite facies, and common to abundant in the granulite facies; this indicates that detrital monazite in pelitic sediments decomposes during low-grade regional metamorphism, but is stable in high-grade metamorphism. The ThO_2 content in monazite from pelitic metasediments rises from about 0.5 percent in the greenschist facies to 10 percent in the granulite facies. A similar relation to temperature and pressure seems to exist in igneous rocks and hydrothermal veins: monazite in granites that crystallized at shallow depth is less abundant and poorer in thorium than monazite in plutonic granites; and monazite in low-temperature veins is thorium-poor, whereas that from high-temperature veins is thorium-rich.

FUELS

PETROLEUM AND NATURAL GAS

Although the Geological Survey does not participate in petroleum exploration, it facilitates private enterprize by gathering and publishing data on the areal geology and stratigraphy of sedimentary basins. Many of the results of this work are described under regional headings on pages A26–A54 but some of the findings that have to do directly with the search for oil and gas are reported here (see page A9 for a description of the relation of marine upwelling to the origin and occurrence of petroleum).

McAlester basin, Oklahoma

Subsurface stratigraphic studies by S. E. Frezon along the northern edge of the McAlester basin indicate that the upper part of the Simpson group thins from south-central to northeastern Oklahoma. North of the Arbuckle Mountains in south-central Oklahoma the equivalent of the Fite limestone of northeastern Oklahoma (Corbin Ranch) rests on the Bromide formation. Northeastward from this area the Bromide and the underlying McLish formation are truncated and in northeastern Oklahoma the Fite rests on rocks of pre-McLish age.

Wilson County, Kansas

Preliminary results of part of a continuing cooperative fuels resources program with the State of Kansas indicate that in Wilson County a close relationship exists between gas accumulation and the tops of structures. Oil, however, accumulated generally in lenticular sandstones of Pennsylvanian age; where the control is stratigraphic, oil occurs on the flanks and in the lower parts of structures as well as on their crests.

Horseshoe atoll, Midland basin, Texas

The occurrence of oil in the Horseshoe atoll, in the northern part of the Midland basin of West Texas, has been described by Stafford (1959) and Burnside (1959). The Horseshoe atoll is an arcuate, reef-like accumulation of fossiliferous limestone, 70 to 90 miles across, that lies more than 6,000 feet below the surface in rocks of Pennsylvanian age. The limestone was extensively reworked and brecciated during deposition. It has an average porosity of about 6 percent, developed primarily by leaching after deposition. Oil is contained in porous zones within the atoll, and in "knolls" on its top which are capped by impervious shale. The Horseshoe atoll is believed to be one of the larger oil reservoirs in the world.

Williston basin, Montana, North Dakota, and South Dakota

A map showing structure contours on the subsurface Piper formation, of Middle Jurassic age, in the Williston basin of Montana, North Dakota, and South Dakota, has been prepared by D. T. Sandberg (1959) in conjunction with a study of well cuttings. This map shows the relations between producing oil fields and major structural features, including the Nesson and Cedar Creek anticlines, Bowdoin and Poplar domes, and the central Montana and Bighorn Mountains uplifts. It also shows many anticlines and other structural features with which oil may be associated.

Utah and southwestern Wyoming

In the southern Kolob Terrace coal field, Utah, geologic mapping by W. B. Cashion indicates that sandstones at the base of the Cretaceous are lenticular and lie in a stratigraphic setting that is favorable for the entrapment of oil and gas. In the northwestern part of the Uinta basin of Utah, he finds that in some areas fluvial beds wedge out up dip between impervious lacustrine beds, and hence provide an environment favorable for the accumulation of oil and gas.

One of the areas in which the concepts concerning the relation of the occurrence of oil to phosphorite facies (see p. A9) may help in defining ground favorable for oil exploration is the fringe area of the Phosphoria formation. In the Bighorn basin of Wyoming, oil derived from offshore deposits of black shale and phosphorite is trapped in porous carbonate rocks and sealed by impervious green and red shales and evaporites. Cheney and Sheldon (1959) have recognized these same facies relations in southwestern Wyoming and northern Utah, and believe that areas within that general region are also favorable for the occurrence of oil.

Alaska

The petroleum possibilities of Alaska have been recently summarized by Miller, Payne, and Gryc (1959). In southern Alaska, six possible petroleum provinces have been delineated. The most promising of these are the Cook Inlet Mesozoic province and the Gulf of Alaska Tertiary province. In these two provinces, which form an arc extending along the southern margin of Alaska from the base of the Alaska Peninsula to the southeastern Alaska panhandle, the geology is comparable to that of the Coast Ranges of Washington, Oregon, and California. Most of the current search for oil and gas in Alaska is concentrated in this belt.

Central Alaska, a region of approximately 275,000 square miles between the Brooks Range and the Alaska Range, is geologically complex and similar to that of the area between the Rocky Mountains and Sierra-Cascade belts of the conterminous United States. Although no deposits of petroleum are known in the region, three pre-Cenozoic provinces (the Yukon-Koyukuk, the Kobuk, and the Kandik) and several large Cenozoic basin provinces deserve further study.

A large area north of the Brooks Range, including the Arctic foothills and the Arctic coastal plain, has good possibilities for petroleum production. Most of the exposed rocks in the area are of late Paleozoic, Mesozoic, and Cenozoic age. In the Arctic foothills these rocks are folded and faulted, and they dip gently seaward, with minor undulations, under the coastal plain. Part of the area is included in Naval Petroleum Reserve No. 4, in which extensive geologic mapping and exploration were carried out in the period 1944 to 1953 in cooperation with the Office of Naval Petroleum and Oil Shale Reserves. The results of this work are being published in Geological Survey Professional Papers.

Origin of helium and nitrogen in natural gas

Analysis of published data shows that all gas fields contain some helium, and that the helium content of natural gas tends to increase systematically with the geologic age of the reservoir rock. Calculations made by Pierce (Art. 37) indicate that the observed rate of increase in helium content with age of the reservoir rock in most gas fields is about what would be expected if the helium were derived from decay of trace amounts of uranium and thorium in the surrounding rocks. Pierce also considers that nitrogen, which in many fields parallels helium in its increase with the age of the reservoir rocks, could be derived from the slow radioactive decay of carbonaceous matter in surrounding rocks.

COAL

Coal studies in progress are of three main types: (a) geologic mapping and stratigraphic studies of specific coal fields; (b) appraisal of coal resources on a state and national basis; and (c) investigation of the petrography and composition of coal.

Geology of specific coal fields

A recently published report by Harbour and Dixon (1955) on the Trinidad-Aguilar area of the Trinidad coal field, Huerfano and Las Animas Counties, Colo., is the sixth in a series on the Trinidad field, which is one of the most important sources of coking coal in the western United States. The Trinidad-Aguilar area has yielded 80 million tons of coal, and still contains nearly 3 billion tons, most of which is suitable for making coke.

More than 3 million tons of high volatile C bituminous coal are present in the Mesa Verde area, La Plata and Montezuma Counties, Colo., according to a recent estimate by Wanek (1959). In the Square Buttes coal field of western North Dakota more than 3 billion tons of lignite have been mapped by Johnson and Kunkel (1959).

Areal mapping of the southern Kolob Terrace coal field, Utah, by W. B. Cashion, shows that the two productive zones in that field contain 3.5 billion tons of coal. Preliminary results of a cooperative investigation with the State of Washington indicate that the southwestern Washington area contains 3.5 billion tons of subbituminous coal (Beikman and Gower, 1959).

In the Homer district of the Kenai coal field, Alaska, Barnes and Cobb (1969) have mapped 30 coal beds 3 to 7 feet in thickness. This coal ranges in rank from lignite to subbituminous B. Indicated reserves total about 400 million tons.

National coal resources

A new estimate of United States coal reserves, incorporating data from many sources, is summarized by Averitt (Art. 39). The tonnage remaining in the ground in the United States on January 1, 1960, totals about 1,660 billion tons, of which 830 billion tons are assumed to be recoverable.

Distribution of minor elements in coal

Zubovic and others (Art. 42), after compiling numerous determinations of the quantities of minor elements in coals, conclude that there are no marked differences in the minor-element content of coals from different areas in the United States. Analyses of sink-float fractions of several coals indicate that the elements whose ions are small and highly charged—Be, B, Ti, V, Ge, and to a lesser extent Ga—are generally associated with the organic fraction of the coal, whereas those whose ions are large—Zn, La, and Sn—are associated with the inorganic fraction. In pairs of chemically similar elements, such as Co–Ni and Y–La, those with the smaller ions (Ni and Y) generally show the greater association with the organic fraction. These findings indicate that the elements abundant in the organic fraction are present as organic complexes—a conclusion strengthened by the fact that the smaller, more highly charged ions generally produce stable metallic-organic complexes (Zubovic and others, Art. 41).

OIL SHALE

Field studies of the oil shale of the Green River formation in Naval Oil-Shale Reserve No. 2, northeastern Utah, show that the principal oil shale zones in the northeastern part thin and intertongue with sandstone in the southwestern part of the Reserve (Cashion, 1959). Estimates of the potential yield of selected oil shale zones 15 feet or more thick in the 140 square mile area of the Reserve, range from 800 million barrels for parts of the deposits yielding 30 gallons of oil per ton, to 3.8 billion barrels for parts of the deposits yielding 15 gallons per ton. A regional study of the geology and oil shale resources of a 1,900 square mile area in the eastern part of the Uinta Basin, Utah, indicates a similar general decrease in the thickness of the oil shale zones from the center of the basin toward its south and east flanks.

Similar facies changes have also been found by J. R. Donnell in the Green River formation in a 1,400 square mile area of the Piceance Creek Basin, western Colorado. The oil shale deposits there are about 2,000 feet thick in the central part of the basin, and they thin and intertongue with sandstone facies along the northeast and southwest flanks of the basin. Continuing studies of subsurface data from the same area by D. C. Duncan indicate that a large but incompletely outlined area in north central part of the Basin contains a sequence of oil shale more than 100 feet thick, with an oil content of 25 gallons or more per ton.

DEVELOPMENT OF EXPLORATION AND MAPPING TECHNIQUES

In connection with its work on mineral deposits, the Geological Survey does considerable research on the development of new methods and tools for geochemical, botanical, and geophysical exploration. Because geologic mapping constitutes a large part of its activity, the Survey also experiments with new methods of mapping and preparing maps for publication. Some of the new developments in these fields are described in the following sections. Reference to others will be found in the list of publications on p. A107–A127.

GEOCHEMICAL AND BOTANICAL EXPLORATION

Since 1946 the Geological Survey has been investigating geochemical methods on the premise that diagnostic chemical patterns exist in the rocks, soils, water, and vegetation in the vicinity of concealed mineral deposits. A major goal of the Survey's work has been to develop rapid methods of chemical analysis suitable for detecting traces of various metals in the field. Some of the methods now available for field determination of metals in soil and rock are listed on the following page. New analytical and prospecting techniques are discussed in subsequent paragraphs.

New analytical techniques

A resin-collection technique has been developed by Canney and Hawkins (Art. 43) for concentrating the ionic constituents of natural waters at the sample site. Its advantages include (a) a much lower limit of detection (fractions of 1 part per billion) than can be obtained with most direct analytical methods, and (b) elimination of the shipment and storage of bulky samples and of possible losses of trace metals from solution prior to analysis.

Sensitivity (in parts per million) of field methods for determination of metals in soil and rock

Element	*Method*	*Sensitivity (ppm)*
Antimony	rhodamine-B	1
Arsenic	mercuric chloride	10
Bismuth	diethyldithiocarbamate	5
Chromium	(oxidation to chromate)	100
Cobalt	2-nitroso-1-naphthol	10
Copper	2,2′-biquinoline	10
Germanium	phenylfluorone	4
Lead	dithizone	20
Manganese	(oxidation to permanganate)	50
Mercury	dithizone	1
Molybdenum	potassium thiocyanate	1
Nickel	α-furildioxime	10
Niobium	potassium thiocyanate	100
Selenium	(reduction to elemental selenium)	50
Tin	4,5-dihydroxyfluorescein (gallein)	10
Titanium	tiron	150
Tungsten	potassium thiocyanate	20
Uranium	potassium ferrocyanide	4
Vanadium	phosphoric acid & sodium tungstate.	50
Zinc	dithizone	20

Molybdenum is particularly useful as an indicator in geochemical prospecting because it is associated with many base metal ores, is readily oxidized during weathering, and in the oxidized form is soluble in waters of widely differing pH. To make better use of molybdenum as an indicator of other metals, a method has been devised that can determine as little as a few tenths of a part per billion of molybdenum in water (Nakagawa and Ward, 1960). In this method, the molybdenum is first collected by a resin, leached, and then determined as the amber-colored molybdenum thiocyanate.

To facilitate botanical prospecting for volatile elements, such as antimony, mercury, and arsenic, F. N. Ward has devised methods for determining traces of these elements in vegetation. Using the reaction of beryllium with morin, he has also developed a modified fluorometric procedure for determining 1 to 10 ppm of beryllium in rocks.

Plastic artificial standards have been developed to replace cumbersome and often unstable liquid standards in field tests for a variety of elements (Hawkins and others, 1959).

Prospecting techniques

In reconnaissance of large areas by geochemical methods based on chemical analysis of the fine-grained fraction of stream sediments, it is usually difficult to distinguish enrichments of metal that are now taking place in streams from enrichments that are related to ore-forming processes. Field studies in Maine by F. C. Canney suggest that many of the false anomalies, at least in glaciated areas, are caused by the scavenging action of the black manganese oxides that coat the pebbles and boulders in many stream courses. Surprisingly large quantities of some trace metals have been found concentrated in these coatings. This scavenging action is being investigated to see if it can be utilized in geochemical surveys.

Chemical analysis of igneous rocks has shown that much of the ore metals in stocks associated with ore deposits was introduced into the rocks and affixed to the surface of dark minerals without inducing any recognizable alteration; a large part can be removed by dilute acids. The content of metals is directly related to the abundance of the metals in the ore deposits themselves (Griffitts and Nakagawa, Art. 45). A high content of copper and zinc in igneous rocks may mark hypogene dispersion halos that extend several miles from centers of mineralization, and these halos may be used in the search for such centers. Roach (Art. 50) finds that the thermoluminescence of the host rocks decreases and the porosity increases with distance away from the base-metal replacement deposits in the Eagle Mine, Gilman, Colo. If further work shows that these relations occur in other districts, they will clearly be helpful in the search for ore deposits.

A prospecting tool that offers considerable promise of being effective in the Basin and Range province is comparison of the metal content of caliche on pediments with that of the alluvium (Erickson and Marranzino, Art. 47).

APPLICATION OF ISOTOPE GEOLOGY TO EXPLORATION

Investigations of the isotopic compositions of lead, oxygen, and sulfur in minerals are leading to conclusions and concepts that bear directly on problems of origin, age, size, and position of ore deposits. Other isotope investigations, bearing less directly on these problems, deal with hydrogen (see p. A68) and the "emanation" isotopes (radon, thoron, actinon) (for example, Tanner, Art. 51), and with age determination (p. A69) by the K/Ar, Rb/Sr, and Pb/U methods.

Isotope geology of lead

An analysis of all available lead-isotope data has been completed by R. S. Cannon, A. P. Pierce, J. C. Antweiler, and K. L. Buck (Cannon and others, 1959). In terms of Pb^{206}, Pb^{207}, and Pb^{208}, about 75 percent of all measured compositions fall within the bounds of an evolution curve predicted from an assumed primordial composition of lead, together with the estimated contributions of radiogenic Pb^{206}, Pb^{207}, and Pb^{208} from breakdown of uranium and thorium. Except for the highly anomalous "J-type," the composition of lead from major base-metal districts is strikingly concordant with the predicted values—so much so that if the ore in a mineral prospect contains lead of divergent composition, there is little probability that the prospect is in a major deposit. There is a close correspondence between leads from ore deposits and those from rocks, which may mean that many, if not most, ore deposits are formed by concentration of elements from sources within the crust, rather than from a deeper-seated source. The data also show, when analyzed for "model" ages, distinct groupings that suggest major metallogenic epochs at 3,000 m.y. (million years), 1,500–2,000 m.y., and 0–500 m.y. The "J-type" leads, most of which are from deposits in the central United States, have highly anomalous compositions, very different from those of leads from otherwise similar deposits of the Mississippi Valley type on other continents, as if the "J-type" leads owed their composition to some provincial phenomenon, as yet unidentified. Uraniferous districts, such as Blind River, Ontario, and the Colorado Plateau, are characterized by leads enriched in Pb^{206} and Pb^{207}, a fact that could serve to guide prospecting for uranium in undeveloped areas.[3]

Oxygen isotopes in ore and gangue minerals

A geologic thermometer that may be of great range and precision, has been tentatively established by R. N. Clayton (of the University of Chicago and the U.S. Geological Survey) and H. L. James. It uses the O^{18}/O^{16} ratios of iron oxides, calcite, and quartz, and is based on the following considerations: (a) the experimentally determined isotopic equilibrium in the system $CaCO_3$–H_2O; (b) the relative isotopic fractionation between calcite and quartz, as determined by measurements of equilibrium pairs from natural environments; and (c) the assumption, based on measurements of materials from many geological environments, that magnetite and hematite undergo little if any isotopic fractionation relative to the solutions from which they are deposited. The isotopic compositions of magnetite-specularite-calcite-quartz assemblages from a number of districts have been measured. Examples of temperatures estimated from these measurements are as follows:

Iron River, Michigan	80°C
Balmat, N.Y. (post-ore supergene mineralization)	110°C
Coeur d'Alene district, Idaho	200°C
Iron Mountain, Missouri	340°C
Iron Springs, Utah	700°C

Data from the Lake Superior region, though incomplete, suggest that the iron oxides of the main ore bodies were formed from solutions isotopically similar to present-day fresh water.

T. S. Lovering, J. H. McCarthy, Jr., and H. W. Lakin are working on a method for indirect determination of oxygen isotopes in carbonate rocks. The oxygen is released from the carbonate by reaction with phosphoric acid, and, as carbon dioxide, is reacted with hydrogen gas to produce water. The density of the water, which is a function of the O^{18}/O^{16} ratio, is then measured by the rate at which it falls through a liquid of nearly the same density. With the apparatus now developed, standardized waters differing in density by one part in four million can be distinguished. It is hoped that the "falling drop" technique will ultimately afford a rapid and inexpensive means of obtaining oxygen isotope data on carbonate rocks, so as to facilitate the search for hydrothermal zoning patterns such as those that surround the ore deposits in the Leadville limestone.[4]

GEOPHYSICAL EXPLORATION

A significant development in the use of geophysics by the Geological Survey during recent years has been the trend towards studying large areas rather than individual features or anomalies. The immediate objective of these regional studies is generally to aid in mapping geology in areas of poor exposures, where mapping by the older methods is difficult, or to determine the depth or configuration of basement rocks or deeply buried magnetic masses. Although the direct search for ore bodies has received less emphasis, it is likely that a study of the geophysical and geological framework to which anomalies must be referred will ultimately result in easier and more certain geophysical exploration for ore bodies.

Information on the development and application of aeromagnetic, radiometric, electrical, and gravity methods follows. New data on the physical properties of rocks, some of which may be useful in exploration, are described on page A56.

[3] Cannon, R. S., Stieff, L. R., and Stern, T. W., 1958, Radiogenic lead in nonradioactive minerals—A clue in the search for uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, 2d, Geneva, 1958, Proc., v. 2, p. 215–223.

[4] Engel, A. E. J., Clayton, R. N., and Epstein, S., 1958, Variations in isotopic composition of oxygen and carbon in Leadville limestone (Mississippian of Colorado) and in its hydrothermal and metamorphic phases: Jour. Geology, v. 66, p. 374–393.

Aeromagnetic methods

The greatest advances in exploration geophysics in recent years have been made in the application of aeromagnetic methods to geologic mapping problems. Practical methods have been developed for calculating second derivatives, and for the upward or downward continuation of magnetic field measurements, and programs have been prepared by Roland Henderson (1960) for making these calculations on high-speed computers; tedious computations, therefore, are no longer a deterrent to the quantitative interpretation of magnetic maps. Magnetic field patterns about prismatic models of geologic structures with a wide variety of dimensions have been determined experimentally and analytically, and catalogs of the results have been compiled. Three-dimensional polar charts for calculating the magnetic effects of a rock mass of arbitrary shape have been developed (Henderson, Art. 52). These interpretation aids have combined to make possible a highly quantitative evaluation of many magnetic field maps.

Magnetic methods can be used for tracing relief and structure in rocks that differ widely in magnetic susceptibility (see Arts. 54, 79, 85, 88, 95, 102, 114, and 158 for discussions of recent fieldwork). Where the magnetic contrasts arise from differences in the magnetic properties of basement rocks, the thickness of sedimentary cover over the basement can be calculated with an error of only 10 to 15 percent. Recent drilling and seismic surveys at three places in Indiana have confirmed the predictions of depth to Precambrian basement rocks made by Zietz and others and recorded on a contour map of the Precambrian surface in Professional Paper 316–B, published in 1958. As this map was prepared almost wholly on the basis of aeromagnetic data, the new information strengthens confidence in depth determinations made by these methods. Magnetic methods can also be used to trace structure in layered rocks in which magnetic contrasts exist, and were, in fact, used to a large extent in making the recently published geologic map of the Iron River-Crystal Falls district of Michigan (James and others, 1960). The application of magnetic methods for this purpose has been extended by the development of a graphical method that makes it possible to determine the dip of a buried geologic structure when the depth to the top of the structure is known (Andreasen and Zietz, Art. 107).

Aerial radioactivity surveys

Recent studies indicate that aerial radioactivity surveys will be a valuable aid in mapping areas of poor exposures and low relief in which the rocks differ moderately in their content of radioactive minerals (Moxham, 1960; Guillou and Schmidt, Art. 55). It has been found that felsic rocks and shales are generally more radioactive than mafic and carbonate rocks. Some of the results of recent field measurements are described on pages A29, A31–A33, and A42.

Electrical methods

Electromagnetic methods and galvanic-electric techniques have been used on a limited scale in Minnesota, Wisconsin, and Maine to determine the structure of metamorphic rocks under alluvial or glacial cover (Frischknecht and Ekren, Art. 56; Anderson, Art. 57). Continuous conductive zones, whose conductivity is probably caused by the presence of a few percent of graphite or carbon, are common in metamorphosed shales and slates, and serve as horizon markers in mapping. In Maine, galvanic-electric methods for measuring resistivity and induced polarization have also shown promise for mapping resistant horizon markers.

C. J. Zablocki has applied an induction logging technique to the measurement of magnetic susceptibility in diamond-drill holes. Susceptibility logs have been run during the past two years in about forty drill holes penetrating magnetite ores in the Lake Superior region, southeastern Missouri, and California. The susceptibilities measured in the holes agreed closely with those calculated from magnetite content. Susceptibility logs generally give a better picture of magnetic distribution than core assays, which must be averaged over several feet of sample.

G. V. Keller has shown that induced electrical polarization is of considerable value in the search for low-grade metallic ores that are not sufficiently concentrated to cause any magnetic, gravity, or electrical conductivity anomaly (see also p. A56). In favorable circumstances, such as those existing in the copper deposits in the Nonesuch shale at White Pine, Michigan, and in the disseminated copper deposits of southern Arizona, induced electrical polarization measurements may be used not only to locate ore bodies but also to estimate their grade. Keller has also developed a system for measuring induced electric polarization continuously by lowering a probe in a drill hole. This method uses an electrode array similar to that normally used in resistivity logging. Current is applied to the electrodes in short pulses, and the transient voltages between pulses are averaged and recorded. The method has been used for logging drill holes in several districts, including the native copper district of northern Michigan, the southern Arizona porphyry copper district, and the eastern Tennessee zinc district. It is useful in determining whether or not ores in a particular district may be located by surface induced-polarization surveys.

Gravity methods

High-speed electronic computers are also being used in calculating the otherwise time-consuming terrain corrections required in gravity surveys (Kane, Art. 59). Gravity measurements are effectively used to determine the depths and configurations of intermontane basins filled with low-density sediments (for example Mabey, 1960), and Davis, Jackson, and Richter (Art. 60) have also used them to delineate areas favorable for the occurrence of chromite in Camagüey Province, Cuba. The accuracy required to measure the small gravity differences that are significant in chromite exploration is attained by using gravimeters that have low scale constants and by frequently checking instrumental drift.

GEOLOGIC MAPPING

The most important advances in geologic mapping techniques have come in the fields of photogrammetry, photogeology, and map drafting. Most Geological Survey research in photogrammetry is done by the Topographic Division and is not discussed here, except to say that the Topographic Division's orthophotoscope has now been brought to a high level of development. Orthophotographs (photographs having a uniform scale as contrasted to the conventional aerial photographs) produced with this instrument are proving to be a fine base for geologic mapping in areas where topographic maps are not available, and they will undoubtedly be used extensively in the future.

Photogeology

Inspection of stereoscopically paired aerial photographs, supplemented by techniques that permit quantitative measurement of relief and of the dip of inclined strata, has been used widely in recent years for reconnaissance geologic mapping. Photogeologic mapping, carefully controlled by field work, is also coming into wider use as a time-saving supplement to field methods in the preparation of standard, all purpose geologic maps. The detail and accuracy with which geometric measurements can be made from aerial photos also make photogeologic methods especially useful in research on certain quantitative geomorphic problems, such as the density, length, and orientation of drainage features in different types of terrane (Ray and Fischer, 1960).

Spectrophotometric research on photos shows that the tonal difference between various rock types can be emphasized by using selected parts of the spectrum in taking aerial photographs (Fischer, Art. 61). This result can be obtained also by rephotographing color photographs through selected filters that emphasize specific lithologic features. Quantitative measurements of photographic tone, determined either from optical density of the negative or light reflectance from a paper print, also may be useful in identifying and evaluating lithologic and geomorphic features.

Although color aerial photographs cannot yet be used in simple plotting systems, Minard (1960) has found them a valuable tool in mapping poorly exposed formations in the coastal plain in New Jersey.

Scribing techniques

The drafting of geologic maps, especially for rapid field compilation and preliminary publication, has been greatly facilitated by the development of scribing techniques—work in which the map-making agencies of the Federal government, including the Topographic Division of the Survey, played a leading role. In these techniques, lines are engraved on coated transparent but actinically opaque (that is opaque to light waves that affect photographic film) dimensionally stable materials. Scribing offers several advantages over pen and ink drafting for the geologist: it is faster and neater; the lines made by the scribing tool are of uniform width; the line placements are more accurate because the lines need not be redrafted by an illustrator for preliminary publication; corrections can be easily made by applying acetate ink or some other material that can be rescribed; and a preliminary map on which geologic boundaries and symbols have been scribed by the geologist in the field can be published with minimum delay. Materials and instruments used in scribing can now be obtained from many commercial distributors of drafting supplies.

GEOLOGY APPLIED TO PROBLEMS IN THE FIELDS OF ENGINEERING AND PUBLIC HEALTH

A few decades ago, the science of geology was used mainly in the search for deposits of usable minerals, but today it is also used to help solve a wide variety of problems related to engineering works, public safety, and public health. Any good geologic map at a scale of a mile to the inch or larger contains information that can be used in selecting, planning, and designing sites for engineering structures or in evaluating the hazards that natural features offer various kinds of human activities. The geologic mapping undertaken by the Survey thus yields much information of present or future value to engineering. The Survey also conducts many investigations to help solve specific problems met in connection with construction, damage caused by earthquakes, landslides or related phenomena, underground testing of nuclear explosives, radioactive waste disposal, and other problems in the field of public health. Results of these studies are described in the following sections.

CONSTRUCTION PROBLEMS

Most of the Survey's work on construction problems is intended to provide information that will aid in the design or construction of a specific highway, airport, dam, or other features. Some of these activities are described here as examples of the use made of geology in construction projects.

Damsite location and sewage system construction

At the request of the Bureau of Reclamation, Reuben Kachadoorian investigated a proposed damsite at Devil Canyon, approximately 125 miles north of Anchorage, Alaska, where the Susitna River flows through a gorge about 600 feet deep and 1,200 feet wide. The foundation of the proposed damsite consists of phyllite cut by numerous steeply dipping shear zones that cross the river approximately normal to its course. The proposed spillway site, located about 1,000 feet south of the river, is a V-shaped valley, originally about 85 feet deep, but now filled by outwash overlain by a thin veneer of morainal debris deposited by an advancing glacier. As a result of the study, the proposed damsite was moved 100 feet upstream from its original location to avoid a large shear zone and the spillway site was also relocated to reduce excavation costs.

In the Puget Sound area, Washington, which includes Seattle and several nearby communities, geologic information developed by H. H. Waldron, D. R. Mullineaux, D. R. Crandell, and L. M. Gard should significantly reduce the cost of constructing a major sewage disposal system. For example, these geologists found that a certain landslide area contains a kame of sand and gravel, and advised that the kame be trenched instead of tunneled as originally planned. Metro engineers estimate that trenching would cost between $100,000 and $200,000 less than tunnelling. The geologists also warned that the valley floor deposits of the Cedar River probably contain "shoestring" channel gravels, which might cause heavy flows of water where the trenches intersected them. Since it would be virtually impossible to outline all the gravel-filled channels in advance, the engineers have tentatively decided to spend less than they had intended on exploratory drilling, and to write specifications that allow for additional payment for any channel gravels intersected by the trenches.

Highway and bridge construction

As a part of a cooperative project with the Massachusetts Department of Public Works, the Survey provides geologic information about the sites of proposed road cuts. Two examples are typical. The first was connected with plans for a cut 100 feet deep along route 495 in Haverhill. From surface mapping and seismic exploration, C. R. Tuttle and R. N. Oldale found that this cut would be entirely in a drumlin. Seismic velocities and previous experience indicated that the material to be removed was a tough, compact till, difficult to excavate, and also that it contained a large proportion of silt, so that after excavation it would be subject to massive solifluction. Several borings were therefore recommended to enable the engineers to design the slope for maximum stability and minimum maintenance. In the second example a 60-foot cut was proposed for a segment of Route 138 in Fall River. A housing development rested at the top of the planned slope. Preliminary seismic traverses showed that the proposed slope would intersect two layers of material that differed in composition and were likely to have different engineering characteristics. Drive sample and core borings were made in order to identify the materials in these layers, and thus to obtain information that would be useful in designing a retaining wall. These studies, made in collaboration with the highway engineers, showed that the upper layer contained weathered carbonaceous to graphitic phyllite that would readily slide, so the engineers recommended a gravity wall with a shear key and a benched slope above the wall.

Detailed geologic studies by Reuben Kachadoorian and Clyde Wahrhaftig, made at the request of the Bureau of Public Roads, have shown that it is feasible to construct a highway through Nenana Gorge in Central Alaska where numerous landslide areas exist, and have led to several recommendations that would protect both the proposed highway and the present grade of the Alaska Railroad. As an example, one recommendation relates to the construction of a bridge across the Nenana River at Moody, Alaska. The west bank of the gorge is underlain by highly fractured and sheared Birch Creek schist, locally overlain by lake clay beds that are highly susceptible to land sliding. Geologic mapping revealed the presence of a large block of relatively unfractured schist suitable for the support of a bridge foundation and so situated as to be in minimum danger from landslides in the adjacent clay beds.

Emergency aircraft landing sites

For 5 years W. E. Davies, G. E. Stoertz, and J. H. Hartshorn have been helping the Air Force Cambridge

Research Center locate natural emergency landing sites for heavy cargo aircraft in the north polar regions. More than 50 sites suitable for the safe landing of the largest aircraft have been identified and 2 of the sites have been tested by aircraft landings. Sites selected for testing are on soils ranging from hard packed clay to gravel. The unique combination of the arid climate and permafrost gives rise to an active thaw zone at the surface which, unlike most active zones, has low moisture content and great bearing strength. Where such soils are on flat outwash plains, flood plains, former lake or lagoon bottoms, and on river terraces they form natural runways that require very little preparation for use by heavy aircraft.

Problems related to permafrost or frost heaving

Mapping of the general distribution of permafrost in Alaska, coupled with other geologic studies, has delineated numerous areas in which highway, bridge, or damsite construction and related activity either will not affect the permafrost or where, when thawed, permafrost will not cause destruction or damage to the structure.

A direct contribution to engineering has been made by a study of the frost heaving of piles (Péwé and Paige, 1959). Many of the wooden pile bridges on the Alaska Railroad are displaced every year by frost heaving, as are many other structures set on piles. Geologic studies of the several factors that influence frost action led to the discovery of better methods for placing piles. It was shown, for example, that piles firmly anchored in permafrost are rarely displaced by frost heave. Moreover, the practice of steam-thawing the holes made for piles delays refreezing and permits seasonal frost action. In some places it was found necessary to insulate the pile footings to inhibit formation of ice. Some of the principles used in these studies will be applicable to construction work in other parts of the United States where frost penetration is deep.

At the request of the Alaska Railroad the Survey examined the foundations of Riley Creek Bridge, near McKinley Park Station, Alaska, to learn the cause of horizontal and vertical movements of the bridge piers. R. Kachadoorian and A. H. Lachenbruch found that the movement was due to the formation of ice lenses beneath the piers as a result of the dissipation of heat more rapidly from the exposed parts of the piers than through the ground surrounding them. They recommended insulating the exposed lateral surfaces of the piers—a relatively inexpensive solution to the problem.

Analysis of thermal measurements made under buildings and roadways shows that the minimum thickness of gravel fill necessary to maintain a perennially frozen sub-grade is strongly influenced by the thermal properties of the sub-grade. Except under favorable conditions, the amount of material required to preserve permafrost by a single layer of fill is too great for practical use. A theory developed for periodic heat flow in a three-layer medium showed that a thin layer of material with relatively low contact coefficient, such as logs or pumice, placed between the fill and subgrade, would greatly reduce the amount of fill required (Lachenbruch, 1959c).

In a cooperative study with the Bureau of Public Roads near Glennallen, Alaska, Green, Lachenbruch, and Brewer (Art. 63) have found that settlement and heaving of roads built on permafrost is caused by the change in the natural heat exchange brought about by the road surface itself. The road surface increases the seasonal range of temperature and hence increases the seasonal depth of thaw. Subsidence results where water from the thawed ground can drain off, and heaving occurs where water, trapped in basins beneath the roadway, refreezes.

Problems related to erosion

C. A. Kaye is studying the geologic factors that influence the pattern, rate, and mechanics of sea-cliff erosion in New England for the purpose of predicting erosion and recommending control measures. He finds that at Gay Head, on Martha's Vineyard, Mass., the cliffs of Pleistocene, Tertiary, and Cretaceous sedimentary rocks are receding 1 to 5 feet a year, largely by landsliding; but cliffs of compact till at Long Island in Boston Harbor recede only a few inches a year; and in hard gabbro along a tidal channel at Nahant, Mass., the rate of abrasion appears to be only a few thousandths of an inch per year.

ENGINEERING PROBLEMS RELATED TO ROCK FAILURE

The failure of rocks when they are stressed, either naturally or artificially, beyond their elastic limit results in a wide variety of phenomena that affect engineering works and other human activities. These phenomena include such things as coal bumps (the bursting of coal seams, part of whose lateral support has been removed in mining), landslides, and earthquakes that result from failure of large segments of the earth's crust. Studies of these phenomena that are directly concerned with engineering problems are described here. Results of investigations of rock deformation that have more general application are described on pages A57–A58.

Coal "bumps"

The response of coal and adjacent strata to stresses induced by mining is being studied by Osterwald and Brodsky (Art. 64), in cooperation with the U.S. Bureau of Mines, in the Book Cliffs coal fields of east-central Utah. Surface and underground mapping at the Sunnyside No. 1 mine has shown that the orientation, relative to the direction of an adit, of the dominant sets of fractures that existed prior to mining determines whether "bumps" are frequent but nonviolent or infrequent and violent. This concept is now being applied in actual mining operations.

Deformation of rocks by nuclear explosions

Surface and underground cracks, faults, and crushed zones produced in bedded volcanic tuff of the Oak Spring formation by conventional as well as nuclear explosives at the Nevada Test Site are being studied in cooperation with the Atomic Energy Commission to determine their relation to lithology and original structures. The effects of conventional and of nuclear explosives cannot be directly compared at small distances from the charge centers because the volume and mass of ordinary explosives and of their gaseous products are much greater than those of nuclear explosives that liberate an equivalent amount of energy. Farther out, the effects are more easily compared, and in some respects they are similar in kind: for both types the extent of fracturing is assymetric; the strongest displacements commonly follow pre-existing bedding planes, joint systems, and faults; and the arrangement of soft and hard tuff beds affects the transmission of seismic energy (McKeown and Dickey, Art. 190). The maximum radial distance from the explosion chambers of fractures in tuffs of the Oak Spring formation scales empirically as the 0.4 power of the energy yield in tons of the explosion for both nuclear and high-explosive tests (Wilmarth and McKeown, Art. 191).

Earthquakes and earthquake-triggered landslides

Mass movement, earthquakes, and subsidence are often unrelated to one another, but in some circumstances they are casually related. Such a relation is strikingly demonstrated by the earthquake that occurred on August 17, 1959, Hebgen Lake, Mont. (Witkind, 1959), which triggered the Madison Canyon landslide—a rockfall avalanche involving some 35 million cubic yards of schist, gneiss, and dolomite (Hadley, 1959a). During this earthquake, an area 27 miles long and 14 miles wide subsided detectably. The maximum subsidence was 19 feet and a tract of about 50 square miles dropped more than 10 feet (W. B. Myers, written communication, 1960). There was almost no elevation above previous levels. The changes of altitude of bench marks as determined by releveling, the tilting of lake shores, and the formation of new fault scarps appear to define a broad basin that plunges gently eastward across the Madison Valley and Madison Range to Hebgen Lake. The subsidence and tilting terminate abruptly northeast of Hebgen Lake, against fault scarps up to 20 feet high, most of which follow faults upon which displacement had occurred earlier in Quaternary time. The two major scarps are on faults controlled by the attitude of bedding in Paleozoic rocks, so the surface fault pattern does not directly indicate the pattern of deep deformation.

The rockfall avalanche that occurred at Frank, Alberta, in 1903 was a similar response to earthquake movements, and recent mapping shows that other rockfall avalanches took place in prehistoric times in the seismically active Northern Rockies. For example, M. R. Mudge has found a rockfall avalanche along the front of the Sawtooth Range in northwestern Montana that involved about 800 million cubic yards of rock. Betty Skipp has found a smaller one in the Maudlow quadrangle, Montana, and W. G. Pierce has identified the natural dam of Deep Lake, Montana, as a rock avalanche that filled the canyon there to a height of about 800 feet.

Giant waves that have repeatedly devastated the shores of Lituya Bay, Alaska, have been found by D. J. Miller (1960a, 1960b) to have been caused by earthquake-triggered rockfall avalanches. Such an avalanche plunged into deep water at the head of this T-shaped tidal inlet on July 9, 1958, generating a gravity wave that swept 7 miles to the mouth of the bay, at a speed of about 100 miles per hour. Trees on the shore of the bay were removed up to a sharp trimline over a total area of 4 square miles and to a maximum height of 1,720 feet, about 4 times greater than the height of any wave swash previously reported. Other trimlines record the heights of earlier waves of this kind: one in 1936 reached 490 feet, one about 1874 at least 80 feet, and one in 1853 or 1854, 395 feet. The frequent occurrence of slides causing giant waves in Lituya Bay is attributed to the combined effect of recently glaciated steep slopes, highly fractured rocks and deep water in the active fault zone at the head of the bay, heavy rainfall, and frequent freezing and thawing. In view of the destructive capacity of these waves and of similar landslide-generated waves in other parts of the world that have been tabulated (Miller, 1960a), it is necessary to consider this potential hazard in any future use of Lituya

Bay or other lakes and bays that adjoin steep, unstable slopes in seismically active areas.

Other landslides and mudflows

In the San Francisco South quadrangle, Bonilla (Art. 66) has mapped and analyzed the origin of landslides as a sample of those that occur in the California Coast Ranges. He finds that 13 of the 16 types recognized in the classification of the Highway Research Board are present in this area; debris slides and earthflows are most numerous, but complex landslides have affected a greater area. More than one-third of the slides have occurred on slopes of 20° to 25°, and about one-sixth on slopes of about 40°.

A preliminary map prepared by McGill (1959) shows all the known active and inactive landslides in the Pacific Palisades area of Los Angeles, where slides have caused considerable damage to houses and interruption of traffic along the Pacific Coast Highway.

In the Puget Sound Basin in Washington, D. R. Crandell and others have recognized many previously unidentified volcanic mudflows of Miocene, Pleistocene, and Recent age; one of these, the 60-mile long Osceola mudflow, was previously regarded as a mass of glacial till. In southwestern Colorado, Crandell and D. J. Varnes have found that the Slumgullion earth flow, which is about 5 miles long, is 700 years old, and that its upper half is still active and moving at a maximum rate of 17 to 19 feet per year.

SELECTION OF SITES FOR NUCLEAR TESTS AND EVALUATION OF EFFECTS OF UNDERGROUND NUCLEAR EXPLOSIONS

Sites for underground nuclear explosions have been selected by the Atomic Energy Commission partly on the basis of studies by the Geologic and Water Resources Divisions of the Geological Survey (Eckel and others, 1959; Péwé and others, 1959; Kachadoorian, 1960). These studies have involved geologic mapping and the collecting of relevant facts about the rocks surrounding the point of explosion (Keller, Art. 183). They have also dealt with such problems as containment of the explosions, distribution of the seismic energy liberated by them (Byerly and others, 1960; Diment, Stewart, and Roller, Art. 70), and the extent to which they contaminated water resources (Clebsch and others, 1959). The Survey has also made numerous special studies of the geologic and hydrologic effects of contained underground detonations of both nuclear and conventional explosives. Some of the results of these studies are summarized here.

Project Chariot

Project Chariot, which is a part of the Atomic Energy Commission's Plowshare Program, is a proposed experiment to determine whether harbors can be excavated by means of nuclear explosives. The Chariot site, on the northwest coast of Alaska near the mouth of Ogotoruk Creek (Kachadoorian and others, 1959 and 1960), was selected by the Commission after it had considered other possible sites (Péwé, Hopkins, and Lachenbruch, 1959). Geologic mapping and other studies undertaken to plan the experiment and evaluate its affects show that the rocks of the Ogotoruk Creek area are folded and slightly metamorphosed sandstone, limestone, chert, argillite, mudstone, siltstone, and graywacke of Early Mississippian (Campbell, Art. 156) to Cretaceous age. The material to be excavated is largely mudstone, siltstone, and sandstone of the Tiglukpuk formation of Late Jurassic age.

Permafrost in the vicinity of the site extends 800 to 1,200 feet below the surface, and all material to be excavated is in the permafrost zone. The moisture content of the rock is estimated to be about 10 percent. Seismic refraction measurements indicate velocities from 11,500 to 14,500 fps, averaging about 13,500 fps. There may be a layer between the depths of 1,000 to 1,750 feet in which the velocity is higher.

The beach at the Chariot site is in a steady-state condition. During ice-free periods the beach sediments are normally transported southeastward along the shore at the rate of about five cubic yards an hour. During heavy storms, however, the rate may exceed 1,000 cubic yards an hour, so that jetties may be required to protect the harbor channel from the material moved during storms.

Unconsolidated material at the site contains shallow aquifers, which during the summer depend upon recharge from surface water. Deep aquifers that receive water from distant sources are present at the site.

The volume of suspended sediment that will be carried into the harbor by Ogotoruk Creek is very small compared with the size of the proposed excavation. During the winter season (mid-October to mid-May) Ogotoruk Creek is frozen and its flow is negligible.

Project Gnome

Project Gnome, also part of the Plowshare Program, is a proposed experiment to determine whether thermal energy and valuable isotopes can be recovered from a nuclear explosion completely contained within a homogeneous salt medium. The explosion will be set off near Carlsbad, Eddy County, N. Mex., 1,200 feet below the surface, in thick salt beds of the Salado formation. Surface and subsurface geologic mapping and other studies made to plan and evaluate this experiment show that in the vicinity of the Gnome site, gravel, sand, and silt of Quaternary age overlie evaporites, sandstone, limestone, dolomite, and redbeds of Triassic and late Permian age (Vine, 1960b). The Permian evaporite sequence consists, in ascending order, of the Castile, Salado, and Rustler formations (Moore, 1959a; C. L. Jones, 1960; Baltz, 1960). No water is known to be moving through the salt of the Salado formation, but there are extensive aquifers, some of which contain brine, in the Salado and Rustler residuum, in the Rustler formation, in the Triassic rocks, and in the unconsolidated Quaternary deposits (Hale and Clebsch, 1959).

Early in 1959 three scaling shots, using 190, 760, and 6,250 pounds of high explosive, were detonated at the Gnome site 1,200 feet below the surface to provide data for calculating motion at various distances from a 9 kiloton (KT) explosion (Roller and others, 1959). The seismic waves generated from these tests and from six routine mine blasts in the Duval Sulphur and Potash Company mine were recorded at the surface at distances of 0.45, 1.8, 3.9, and 9.7 miles from ground zero. Byerly and others (1960) have calculated from these data that the particle displacement, velocity, and acceleration produced in the potash mines near Carlsbad by a 9 KT explosion of TNT at the Gnome site—a distance of 46,000 feet from the nearest potash mine—would not exceed:

Displacement	0.1 –0.2 cm
Velocity	1.5 –3.0 cm per sec at 2 cps
	2.5 –5.0 cm per sec at 4 cps
Acceleration	0.02–0.04 g at 2 cps
	0.06–0.12 g at 4 cps

These motions are less than those recorded at a distance of 90 feet from a routine 75-pound dynamite blast in a potash mine.

Nevada Test Site

The Nevada Test Site is the continental testing facility of the Atomic Energy Commission where performance of nuclear explosives has been studied during past test operations and where experimental nuclear reactors are being studied. The Geological Survey advises the Commission on three essential points—selection of sites for contained underground tests, seismic effects both on and off the test site (Diment, Stewart, and Roller, Art. 70), and ground-water contamination problems (Clebsch and others, 1959). In carrying out these responsibilities, extensive surface and underground geologic mapping (Wilmarth and McKeown, Art. 191), geophysical surveys (Diment, Healey, and Roller, Art. 69), and hydrologic studies have been conducted both before and after explosions, and have been correlated with numerous measurements of chemical, petrographic, mineralogic, and physical properties (Wilmarth, Botinelly, and Wilcox, Art. 67).

All contained underground tests of conventional and nuclear explosives have been in the bedded volcanic tuff of the Oak Spring formation, which is several thousand feet thick, relatively uniform, and easily tunneled (Keller, Art. 183). The Rainier underground nuclear explosion was equivalent to 1.7 KT of conventional explosives, and was at a depth of 900 feet below the surface. The explosion formed a breccia zone 140 feet in diameter in the horizontal plane. The breccia contains radioactive glass, angular to subrounded phenocrysts, and xenoliths 0.3 to 3 feet across in a fine-grained matrix of comminuted tuff. The matrix is characterized by an abundance of hairline fractures, which generally do not cross the phenocrysts or xenoliths, thus indicating that most of the deformation was taken up by the soft matrix. The glass and the radioactivity are mostly confined to the breccia zone, and gamma radiation surveys of the drill holes and mapping in the exploratory tunnel driven after the explosions have shown that they are very irregularly distributed (Bunker, Diment, and Wilmarth, Art. 68). Most of the radioactivity is several tens of feet below and to the northwest of the point of detonation.

Fracturing both in the Rainier tunnel and on the surface, and spalling in the tunnel were observed at considerable distances outside the breccia zone. The tunnel collapsed to a distance of 200 feet from the explosion chamber. Severe spalling occurred in the tunnel at distances of 200 to 400 feet, and several new fractures were produced at distances as great as 1,100 feet. Four inches of movement were observed on a pre-existing fault 1,400 feet from the explosion. The only surface effects were small fractures, largely along pre-explosion joints, and rock falls along the steep topographic scarp beneath which the explosion was detonated (Wilmarth and McKeown, Art. 191).

As a result of the Rainier explosion, the rocks adjacent to the chamber were brecciated. Their porosity increased about 30 percent, and their permeability increased an undetermined amount, while the percentage of water saturation decreased about 30 percent, the acoustic velocity about 70 percent, and the compressive strength more than 50 percent. The decrease in water saturation is approximately equal to the increase in porosity, which suggests that little water was driven out by the explosion. The rocks surrounding the breccia zone, out to about 110 feet from the explosion, are highly fractured and have low compressive strength, low dilatational velocities, and high permeability.

The hydrologic effects of the Rainier, Logan, and Blanca underground nuclear explosions are due to changes in rock characteristics that directly or indirectly control (a) volume of water in storage, (b) rate and direction of ground-water movement, and (c) chemical and radiochemical equilibrium between the rock and its contained water. The radius of effect is small compared to the probable extent of the perched water zones below each explosion. Water samples from the zone affected by the Logan explosion, together with leaching experiments on slightly radioactive rock from near the Rainier explosion, indicate that some radioisotopes are taken into solution by percolating ground water. Movement of contamination from the nuclear explosions would probably be retarded by a slow rate of groundwater movement, low solubility of the explosion-produced glass containing most of the radioisotopes, and ion exchange of radioisotopes between ground water and rocks.

The position and movement of ground water may be partly controlled by the configuration of the buried Paleozoic bedrock surface under Yucca Valley, where the water table is about 1,500 feet below the surface (Diment, Healey, and Roller, 1959). Gravity and seismic data indicate that the alluvium and tuff overlying the bedrock are thickest in a narrow north-trending trough in the eastern part of Yucca Valley, and that they are there more than 3,500 feet thick. A series of gravity highs, bordering the trough on the west, together with refraction seismic measurements, indicate a buried bedrock ridge whose top is locally within 100 feet of the surface, and two drill holes have confirmed this.

Gravity, seismic, and magnetic surveys have helped define the configuration of the buried Paleozoic bedrock surface under Yucca Valley. This surface may partly control the position and movement of ground water (Diment, Healey, and Roller, 1959).

RADIOACTIVE WASTE DISPOSAL INVESTIGATIONS

Studies by the Geologic Division bearing on the disposal of radioactive wastes deal with the physical chemistry of ion exchange, specific sorption of strontium or cesium by certain minerals, and ion exchange and other properties of soils and rocks near reactor sites. In addition, wells or drill holes at radioactive waste disposal sites are being studied by gamma-ray logging techniques. Geologic information is being compiled on sedimentary basins that might be suitable for underground storage of radioactive liquids. Other investigations of waste disposal are being undertaken by the Water Resources Division of the Geological Survey, but these are not reported here.

Geochemical studies

The ion-exchange (or scavenging) properties of crandallite ($CaAl_3(PO_4)_2(OH)_5H_2O$) with respect to strontium were investigated by Irving May during the past year. Strontium solutions "spiked" with radioactive Sr^{89} were passed through columns of crandallite and crandallite-sand mixtures, to determine the effects of Sr concentration, pH, temperature of the influent solution, and the texture (mixture with sand) of the column packing. Crandallite was found to sorb strontium fairly readily from solutions more basic than pH 5.

Studies of the ion-exchange characteristics of American and South African vermiculites made by C. R. Naeser and Marian Schnepfe (Art. 71) show that vermiculite sorbs cesium and holds it firmly at pH values above 3. This reaction is reversed when pH values are less than 1. Aluminum causes virtually no interference in sodium-saturated vermiculite at pH 12.6.

Hydrogen forms of montmorillonite were titrated with NaOH as a part of a general study by Dorothy Carroll and A. M. Pommer (Arts. 198 and 199) of the mechanisms of ion exchange. The potentiometric titrations gave strong evidence that the ions are placed in the octahedral and tetrahedral positions of the layered structures. Similar studies were extended to "illite," kaolinite, halloysite, and NH_4-saturated vermiculite.

Information on ion exchange and related characteristics of the soils and near-surface bed rocks of the Oak Ridge, Tennessee area, compiled by Dorothy Carroll, indicate that the ion-exchange capacities of soils derived from the limestones, shales, and sandstones of Cambrian and Ordovician age range from 3 to 15 meq per 100 g, and those of the rocks from which the soils were derived from 5 to 28 meq per 100 g. Most of the ion-exchange capacity of these soils is due to vermiculite, "illite," and kaolinite.

Clarence S. Ross has identified the cause of localization of a radioactive material in Bandelier rhyolite tuff of Smith (1937) that had been treated with liquid waste. He found by a combined petrographic, autoradiographic technique that the small areas of higher radioactivity were not in the original constituents of the tuff but in materials that had been picked up by the tuffs. Fragments of these alien materials had been oxidized and limonite had formed within or around them.

Sedimentary basin studies

Storage or disposal of radioactive wastes at depth in salt deposits and permeable beds in deep sedimentary basins is considered potentially feasible.

In the San Juan Basin, according to C. A. Repenning (1959), there are four types of reservoir rocks that might be used for storage of wastes: gypsum, limestone, shale, and sandstone. Gypsum appears to be most useful for disposal of sintered waste. Limestone could be suitable for storage of liquid waste, but may prove to be leaky. Shale, in which reservoirs could be constructed by hydraulic fracturing or deep-seated explosions, would be relatively leak-proof. Sandstone would have the advantage in respect to heat control.

As a result of an analysis of the geology of the Central Valley of California, Repenning concludes that the eastern side, as far south as Fresno, appears to be the most promising area for the selection of a waste-disposal site. South of the Stockton arch, sandstone beds tongue out westward into impermeable shale units; in some places along the eastern side of the valley they are warped upward and are truncated and sealed by younger shale. North of the arch the westward-thinning sandstone tongues are less abundant and have not been warped and truncated. A study of hydrologic conditions might reveal places where eastward migration would be slow enough to stay within safe limits.

Geophysical studies

Carl Bunker, using newly modified and calibrated instruments, has made gamma-ray logs of drill holes at the Nevada Test Site before and after injection of radioisotopes. His results show little horizontal or lateral leakage of the injected radioisotopes into the surrounding rock from a specially designed and installed tile field. The radioactivity was too weak to enable him to make gamma-ray spectral measurements of the waste.

Two models of pressure apparatus have been built by E. C. Robertson and R. Raspet to test cylindrical rock samples under biaxial loading by applying pressure hydrostatically to the sides but not the ends of the sample. Biaxial tests show the actual, higher strength and elasticity of rock in place and give more uniform numerical results than the more commonly used uniaxial tests. They thus help to measure the physical properties of host rocks for radioactive wastedisposal in natural environments—properties that determine, for example, the host rock's ability to confine wastes under the elevated pressures and temperatures that may develop after injection of radioactive materials.

MEASUREMENT OF BACKGROUND RADIATION

Owing to the increased use of nuclear power and processing facilities, and to the proposed use of nuclear energy for harbor construction and other experimental purposes, it has become necessary as a precautionary measure to determine the natural background radioactivity in the many areas. In July, 1958 the Geological Survey, on behalf of the U.S. Atomic Energy Commission, began a nationwide program of aerial radiological monitoring surveys (ARMS). The purpose of the program is to obtain data for appraising changes in environmental levels of radiation brought about by nuclear testing programs, by operation of reactors and other nuclear facilities, and by radiation accidents. Most of the ARMS work has consisted of surveying the area extending about 50 miles outward from the center of several reactor and major production facilities. Between July 1958 and January 1960 about 96,000 traverse miles were flown, surveying about 110,000 square miles in 11 areas in the United States. Some of the results of ARMS surveys that are of interest in areal geology are described on pages A29, A31–A33, and A42.

DISTRIBUTION OF ELEMENTS AS RELATED TO HEALTH

Although medical researchers have long been studying the physiological effects of a few elements in the geologic environment—iodine, selenium, and fluorine, for example—the work done hitherto in this general field has not been extensive, and few geologic studies have been undertaken for the specific purpose of analyzing such problems. One such study, however, was begun in 1956 in Washington County, Maryland, on behalf of the National Cancer Institute, which, in cooperation with the Washington County Health Department, is making an intensive study to relate environmental conditions to incidence of cancer. The geologic part of this study consisted of aerial and ground radioactivity surveys to measure gamma-radiation intensities emitted by various rocks, and of botanical and geochemical studies to learn whether the soils and plants contain excesses or deficiencies of elements that might be related to the incidence of cancer. These surveys show relatively small but distinct local differences in radiation intensity that can be correlated with the geology, and an unusual distribution of elements that appears to be related to soil type. Some soils, for example, apparently contain unusually large amounts of titanium, chromium, and lead, and unusually small amounts of iron, zinc, and barium. Nitrates, also, are highly concentrated in some of the ground water and vegetation. The significance of these findings with respect to cancer incidence is being assessed by the National Cancer Institute.

During the past year, Fleischer and Robinson summarized for the U.S. Public Health Service the available data on the geochemistry of fluorine. Of special interest is a map they have prepared showing the maximum reported fluorine content of ground water in each county of the United States. These range from less than 0.1 to 38 ppm. Waters containing more than 1.5 ppm F are generally considered to cause mottling of teeth; such waters occur in more than half the counties of the United States. Recent work by H. A. Powers suggests that in many western and central States there is a connection between high-fluorine waters and the distribution of volcanic ash, which averages about 1100 ppm F.

Attention should be called to the fact that extensive data on the chemical composition of rocks, minerals, and waters are already available and could serve as the basis for other studies of the physiologic effects or hazards of the distribution of elements.

Aluminum, sodium, and manganese are among the elements most susceptible to neutron-induced radioactivity resulting from use of nuclear weapons or devices. At the request of the U.S. Army Corps of Engineers, Burns (Art. 73), has examined means of predicting geographic variations in the content of these elements in rocks when direct sampling is impracticable. As a first step, he has defined the range in the content of aluminum, sodium, and manganese in several groups of common rocks. The results indicate that the aluminum and sodium content of rocks of igneous origin can be predicted from simple lithologic descriptions with at least 80 percent probability of correctness within a factor of 2. Predictions of the manganese content of these rocks, and of the sodium and aluminum of rocks of sedimentary origin, would be of intermediate reliability. Predictions of manganese in rocks of sedimentary origin would have only a low degree of reliability—at least 70 percent probability of correctness within a factor of 5.

An interesting by-product of one of the Survey's investigations came as the result of Frank Senftle's development of a sensitive device to measure magnetic susceptibility in rocks (see p. A56). Using this instrument, he has made magnetic measurements on cancerous tissue specimens for the National Cancer Institute. Two rats of the same species were selected for the experiments. A cancer was induced in one of the animals and was allowed to grow for about four weeks. Before the cancer was allowed to affect the normal activity of this animal, the livers of both animals were removed, together with some of the cancerous tissue. These materials were then immediately quick-frozen in liquid nitrogen to prevent decay of the cells. Magnetic measurements were then made at liquid-nitrogen temperatures to preserve the samples throughout the measuring period and also to enhance, if possible, their magnetic susceptibility. The liver from the cancerous rat showed a definite ferromagnetic effect, while that from the normal rat showed none. The cancerous tissue itself, however, is nonferromagnetic and is more diamagnetic than the healthy tissue, which seems to indicate a depletion of iron.

REGIONAL GEOLOGY

The field studies described in the preceding pages are undertaken to solve known problems of economic importance, but most of the Geologic Division's field work has the broader purpose of defining the composition, structure, history, and origin of the rocks that compose the earth's crust in the United States. It is these studies that often provide the first clue to the location of new mineral districts, that make it possible to search intelligently for concealed deposits and appraise the potential mineral resources of various parts of the country, and that provide background information useful in choosing construction and test sites and in planning new highways and other engineering works.

The chief method used by the Survey to achieve these objectives is geologic mapping, mostly on scales of 1:24,000, 1:62,500, and 1:250,000. Regional geophysical, geochemical, stratigraphic, and paleontologic studies, however, also play an important part. Some of the important results obtained during fiscal 1960 in this program are described in the following pages for the country as a whole and for its major regions (see fig. 1).

SYNTHESIS OF GEOLOGIC DATA ON MAPS OF LARGE REGIONS

Utilizing information generously furnished by State surveys, private companies, and universities as well as its own data, the Geological Survey compiles and publishes several kinds of maps on a national or larger scale. It also collaborates with scientific societies in preparing, and sometimes publishing, maps of this type. Several such maps, described below, reached advanced stages of compilation or were completed during the year. Others in progress include:

1. Geologic map of North America, scale 1:5,000,000. This map is being compiled by a committee of

FIGURE 1.—Index map of the United States, exclusive of Alaska and Hawaii, showing the boundaries of regions referred to on pages A28–A44.

the Geological Society of America, E. N. Goddard, University of Michigan, Chairman.

2. Basement rock map of North America from 20° to 60° N. latitude, scale 1:5,000,000. This map is being compiled by a committee of the American Association of Petroleum Geologists, P. T. Flawn, University of Texas, Bureau of Economic Geology, Chairman.

3. Coal fields of the United States, by James Trumbull. Scale 1:5,000,000.

4. Mineral distribution maps, scale 1:2,500,000. Compiled, under the direction of P. W. Guild and T. P. Thayer, for 34 metals and industrial minerals.

5. Paleotectonic maps of the Pennsylvanian system, by E. D. McKee and others.

6. Absolute gravity map of the United States, scale 1:2,500,000. This map is being compiled by the American Geophysical Union Committee for Geophysical and Geological Study of the Continents, G. P. Woollard, University of Wisconsin, Chairman.

Tectonic map of the United States

A new tectonic map of the United States, exclusive of Alaska and Hawaii, on a scale 1:2,500,000 is nearly completed. It was prepared as a joint undertaking by the American Association of Petroleum Geologists and the Geological Survey under the direction of G. V. Cohee and replaces the tectonic map published by the Association in 1944. Two examples will suggest the scope of advances since the previous version. Structure in thousands of square miles in the Pacific Coast states, the Great Basin, the Lake Superior region, and northern New England that, for lack of information, had to be omitted or sketched diagrammatically in 1944, is now reasonably well portrayed. Buried structures in such areas as the Colorado Plateau, the Mid-Continent region, and the Appalachian basin, which in 1944 had to be contoured piecemeal and on as many as four datum surfaces, are each now contoured on a single datum.

Paleotectonic maps of the Triassic and Permian systems

The long-term program for preparing paleotectonic maps of each of the systems has been underway since 1953. The first folio, on the Jurassic system, was published in 1956. The second, on the Triassic, was issued in 1960 (McKee and others); a few of the conclusions from this study may be mentioned to indicate its scope.

In Early Triassic time a miogeosyncline extended from southern California through the eastern Great Basin into western Wyoming. East of the miogeosyncline, normal marine shelf deposits are well represented; evidence for a eugeosyncline west of the miogeosyncline is lacking. During Middle and Late Triassic time, on the other hand, a eugeosyncline became established in the Cordilleran region; the area bordering the major marine depositional trough on the east was uplifted, and numerous elliptical basins were filled with continental sediments of Late Triassic age. In eastern United States several large structural troughs developed.

Maps and text for the Permian system were completed by E. D. McKee and others in 1960 and are now in review. Major tectonic elements evident from this study include a prominent eugeosyncline in the western Cordillera during much of Permian time. An adjacent miogeosyncline on the east was separated from the eugeosyncline by a narrow belt of intermittently positive areas in central Nevada and northern Idaho; ocean currents flowing southward along the miogeosynclinal belt furnished upwelling cold waters along its eastern margin from which were deposited phosphorite, chert, and carbonate in western Wyoming and adjacent states. Much of the Western Interior during Permian time, from the Dakotas to Texas, was a relatively stable shelf on which warm marine to supersaline waters deposited red beds, extensive carbonate beds, and, in isolated basins, thick evaporite sequences. The southernmost part of the shelf, however, passed abruptly into deep marine basins and embayments in Texas and New Mexico; thick biostromal and reef limestones were deposited along the margins of these basins. The shelf was bordered on the east and north by broad, low to moderately high positive areas. The moderately high ancestral Rocky Mountains and Uncompaghre Uplift were active in Colorado and shed coarse detritus. Along the southern margin of the country, tectonic activity of the Ouachita orogenic belt, greatest during Pennsylvanian time, continued into early Permian time and contributed to the thick detrital sequence present in the Val Verde trough. In the eastern United States only lowest Permian rocks are now preserved in the Dunkard basin, where drainage was to the northeast, rather than to the west as it had been in Pennsylvanian time.

Epigenetic uranium deposits in the United States

Three maps, on a scale of 1:5,000,000 have been published recently showing the distribution of epigenetic uranium deposits in relation to a) continental sedimentary rocks, b) pre-Late Cretaceous crystalline rocks, and c) Late Cretaceous and younger igneous rocks (Finch and others, 1959; see also p. A11).

NEW ENGLAND AND EASTERN NEW YORK

Major geologic mapping programs are underway in cooperation with the Commonwealth of Massachusetts, and the States of Rhode Island, and Connecticut, and field studies related to investigations of mineral deposits are in progress in Maine, Vermont, and eastern New York. Some of the findings of these studies that contribute to knowledge of the regional geology are described below (see p. A6 for information on talc, and asbestos deposits and p. A67 for information on regional metamorphism).

Regional geologic mapping

A geologic map of north-central Vermont compiled by W. M. Cady covers an area of about 1,800 square miles that straddles the axis of the north-trending Green Mountain anticlinorium, and includes the zone of lateral transition from rocks of carbonate-quartzite assemblage, in the Cambrian of the Champlain Valley, to metamorphic rocks originally of graywacke-shale assemblage, in the Cambrian in and east of the Green Mountains.

A. J. Boucot and others (1960) have compiled a map of an area of 12,000 square miles in northern Maine. This map includes the Moose River synclinorium and shows the distribution of rocks of Cambrian through Devonian age; it includes a compilation of aeromagnetic surveys.

P. M. Hanshaw and P. R. Barnett (Art. 76) have found that volcanic units in the Triassic of Connecticut contain more boron than do the intrusive rocks and that their chromium and nickel contents are useful in identifying individual basalts in mapping.

Stratigraphic and lithofacies studies in Vermont and Maine

Cady (1960), collaborating with P. H. Osberg of the University of Maine, has made a stratigraphic correlation between the unmetamorphosed rocks of the miogeosynclinal zone west of the Green Mountains and the metamorphosed rocks in the eugeosynclinal zone farther east on the basis of a few distinctive lithologic units in the graywacke-shale assemblage (Cady, 1960, p. 548).

The stratigraphic succession in northern Maine has been established chiefly through the studies of A. J. Boucot in and near the Moose River synclinorium, which contains about 10,000 feet of upper Lower Devonian strata, chiefly dark sandstone and slate with subordinate amounts of rhyolite. These are underlain on the flanks of the synclinorium by ancient erosional remnants of Cambrian through lower Lower Devonian formations. The Cambrian and Ordovician rocks are chiefly slate and graywacke but are interbedded with volcanic rocks of various kinds and unknown thickness. Some of the granitic rocks in this area are also Ordovician (Neuman, Art. 74). The Silurian and lowest Devonian rocks, which are as much as 4,000 feet thick, consist of calcareous sandstone and siltstone, arkose and arkosic conglomerate, and limestone and limestone conglomerate. Rocks west and southwest of Jackman, along the international boundary, that had previously been assigned to the Cambrian or Ordovician or both, have been found by A. L. Albee to rest on an unconformity that is older than Late Silurian age. These rocks are intruded by intrusive rhyolitic rocks of Early Devonian age and by granitic rocks that are younger than Early Devonian.

Tectonic studies in Connecticut and Vermont

C. E. Fritts has found a fault contact along the western boundary of the Triassic rocks of the Connecticut Valley, where an east-dipping "pre-Triassic peneplain" was mapped by W. M. Davis. The relief on the "pre-Triassic" surface is as much as 1,000 feet in a horizontal distance of 1 mile, which supports the growing belief that Davis' interpretation was incorrect.

Restored sections constructed transverse to the belt of early and middle Paleozoic rocks of the Appalachian geosyncline in northern Vermont show eastward offlap of both the graywacke-shale assemblage and volcanic rocks. The western margin of the longitudinal zone of greatest mobility (eugeosynclinal zone) must therefore have moved eastward across the geosyncline (Cady, 1960, p. 557, pl. 2). This inference is confirmed by the ultramafic rocks, which are of Ordovician age in the western part of the geosynclinal belt, but which include some younger than Ordovician in the eastern part.

Geophysical surveys

Aerial radiological surveys in southern New England and adjacent parts of New York show a good correlation between radioactivity and bedrock geology. According to Peter Popenoe, the highest radioactivity was recorded over the Hudson Highlands in New York, the Hartland formation south of Waterbury, Connecticut, granitic gneisses in Connecticut and Rhode Island, and the cores of gneiss-capped domes in Connecticut.

Much aeromagnetic mapping has been done in the Adirondack Mountains of New York (where, according to J. R. Balsley, seven iron ore deposits have been discovered by aeromagnetic surveys), New Hampshire, and northern Maine.

In Maine, the aeromagnetic data are a valuable aid in geologic mapping, for the major geologic units there have different magnetic properties. For example the magnetic susceptibility of argillite, slate, and sandstone is usually negligible; that of granite, rhyolite, and pyrrhotitic slate is usually less than 1×10^{-3} cgs; and that of diorite, diabase, greenstone, gabbro, and serpentine is generally greater than 1×10^{-3} cgs (Allingham, Art. 54). Electromagnetic methods are also being used in Maine for mapping structure in areas that contain conductive shales (generally graphitic or pyritic) (Frischknecht and Ekren, Art. 56).

Ages of intrusions in the northern Appalachians

Potassium-argon and rubidium-strontium age studies by H. Faul in cooperation with a number of other geologists indicate that there were at least six distinct cycles of intrusion (or metamorphism) in the northern Appalachians, tentatively dated as follows:

Millions of years ago	
460	Represented in Maine by a single body of gabbro south of Katahdin.
400	Recorded in the granites of the Chiputneticook Lakes, the Calais area, Mt. Desert Island and Vinalhaven.
360	Encountered in a widespread network of samples from New England, Nova Scotia and the mid-Atlantic states.
310	Represented by still fragmentary data from the New Hampshire magma series and the pegmatites of southern Vermont and New Hampshire.
260	Connecticut pegmatites.
190	White Mountain magma series.

If the episodic character of these events in the northern Appalachians can be clearly established and correlated, the information should increase understanding of the tectonic history of the eastern margins of the North American continent.

THE APPALACHIANS

Geologic work in the Appalachian region is in progress in several areas in the Valley and Ridge, Blue Ridge, and Piedmont provinces. Salient results of current studies are as follows:

Stratigraphic and geomorphic studies in the Valley and Ridge province

The surface of unconformity that separates Lower and Middle Ordovician rocks in southwestern Virginia and eastern Tennessee has been found by Harris (Art. 83) to have as much as 170 feet of relief. Studies in progress by Helmuth Wedow, Jr., in the Tennessee zinc districts suggest that solution channels below this unconformity are controlled by pre-Middle Ordovician structures and that the unconformity is one of minor discordance.

Englund and Smith have found that Lower Pennsylvanian strata in the basal beds of the Lee formation and Upper Mississippian beds of the Pennington formation intertongue in eastern Kentucky and southwestern Virginia. This suggests that the faunas of Late Mississippian age (Chester) and the floras of Early Pennsylvanian age (Pottsville) overlap and are partial time equivalents. Similar intertonguing of Upper Mississippian and Lower Pennsylvanian strata has been found in the Anthracite region of eastern Pennsylvania.

Hack and Young (1959) have demonstrated that the intrenched meanders of the North Fork of the Shenandoah River are caused by strong planar and prismatic structures in the Martinsburg shale that favor northwest-southeast differential erosion. These meanders indicate long-continued deep erosion in the Valley and Ridge province instead of the multiple erosion cycles widely assumed heretofore (see also p. A55).

Structural studies in eastern Pennsylvania and New Jersey

Structural studies in the valley of the Delaware River of New Jersey and eastern Pennsylvania by Drake and others (Art. 80) show that at many localities Paleozoic rocks are separated from Precambrian rocks by decollements.

Arndt and Wood (Art. 81) have recognized five structural stages in the Appalachian orogeny in the Anthracite region of eastern Pennsylvania. They infer from the southeastward increase in structural complexity of the Valley and Ridge province that the orogeny progressed northwestwardly across the region. If this is true, the Appalachian orogeny probably was progressive elsewhere, for structural complexity increases southeastward throughout the Valley and Ridge, Blue Ridge, and Piedmont provinces.

Geologic results of aeromagnetic surveys

Aeromagnetic surveys made in cooperation with the Pennsylvania Topographic and Geologic Survey have traced local magnetic facies in the metamorphic and igneous rocks of the Piedmont between outcrops, under heavy soil, under less magnetic metamorphic rocks, and under Cambrian, Ordovician, and Triassic sedimentary rocks. In the vicinity of Allentown, Pennsylvania, the magnetic data indicate that the Precambrian rocks exposed at some localities do not extend to great depth (Bromery, 1959). Near Buckingham, about 25 miles southeast of Allentown, the magnetic data show that the Triassic basin is only 7,000 feet deep—considerably less than previously thought (Zietz and Gray, Art. 78).

Aeromagnetic anomalies in southwestern Virginia and eastern Tennessee indicate that depth to basement increases southeastward and averages about 17,000 feet (King and Zietz, Art. 88).

Geologic mapping in North and South Carolina

Overstreet and Bell (Art. 87) have found a belt of low-rank metasedimentary and metavolcanic rocks extending across South Carolina into Georgia that is probably equivalent to the Kings Mountain belt farther northeast. They also found several small granite plutons of uncertain age in the eastern Piedmont, where earlier maps showed batholiths elongated northeastward. Similar granite bodies have been found in the Concord quadrangle of North Carolina by geologic mapping (Bell, Art. 84), supported by aeromagnetic and aeroradiometric surveying (Johnson and Bates, Art. 85). Within this quadrangle is a large circular intrusion which was formerly thought to be a ring-dike but has now been found to consist at the surface of two disconnected masses of syenite that partly enclose a mass of gabbroic rocks. Overstreet and Bell (Art. 87) have discovered other similar circular and ring-shaped intrusions of syenite(?) and gabbro in western South Carolina. Two distinct periods of mineralization have been recognized in the Concord area (Bell, Art. 84): the earlier one, associated with the granite plutons, deposited chiefly gold, tungsten and base metals, and the later one, related to the syenite-gabbro complex, chiefly zinc.

In the so-called "slate belt" of the North Carolina Piedmont, A. A. Stromquist, who is mapping the Denton quadrangle, and J. F. Conley of the North Carolina Division of Mineral Resources, who is mapping the adjacent Albermarle quadrangle, have for the first time established a stratigraphic sequence for the "volcanic slates" (Stromquist and Conley, 1959). A major unconformity separates an upper volcanic unit from an underlying more folded volcanic and sedimentary unit of higher metamorphic grade.

In the Grandfather Mountain area of North Carolina, detailed quadrangle mapping by Bryant and Reed (1959) shows this area to be a window in an overriding plate of crystalline rocks. The window exposes not only the basement rocks, but also the Chilhowee group of Early Cambrian and Cambrian(?) age, and the Ocoee group, of Precambrian age. Lesure's (1959) studies west of this area indicate that the mica pegmatites of the Spruce Pine district were emplaced before the thrusting. East of the window Reed and Bryant (Art. 86) have found a belt of retrogressively metamorphosed rocks along a topographic lineament in line with the Brevard belt of low-grade metasediments to the southwest. The lineament appears to mark a major fault of undetermined nature, which separates the rocks of the Inner Piedmont from those of the Blue Ridge.

ATLANTIC COASTAL PLAIN

Because the bedrock of the Atlantic Coastal Plain is poorly exposed, geophysical methods are especially useful there, and most of the new information on the geology of the Coastal Plain stems from their use. Results that add to our understanding of the geology of the coastal plain are described below. Information on clay and phosphate deposits is given on page A7.

Interpretation of aeromagnetic measurements on the Atlantic Continental shelf and in Florida

Aeromagnetic profiles over the continental shelf and continental slope between Bermuda and the east coast of North America, flown in cooperation with the Office of Naval Research, and a set of six 400-mile profiles southeast of Chincoteague Bay, Maryland, show a prominent and more or less continuous magnetic anomaly of 300 to 500 gammas parallel to the outer edge of the continental shelf (King and others, 1960). Large gravity anomalies of comparable width have been observed in the same area by the Lamont Geological Observatory, but these can be accounted for by crustal thinning and may be only indirectly related to the magnetic anomaly. A basement ridge also parallels the outer edge of the continental shelf, according to Lamont seismic data, but calculations show that the basement rocks must have a higher-than-average susceptibility to produce a magnetic anomaly of the observed size from topography alone. Therefore the anomaly may be at least partly the expression of a mass or series of masses of more magnetic rock, perhaps intrusives, along the outer edge of the continental shelf. Estimates of depth to basement made from aeromagnetic data at selected points on the profiles agree well with depths previously found from seismic measurements.

A regional magnetic map of Florida recently compiled by King (1959a) indicates that, beneath the sedimentary rocks of the Coastal Plain, Florida is divided into two tectonic provinces, separated by a zone of intrusive rocks. The northern province, in the northeastern part of the State, has well-defined northeasterly magnetic trends parallel to those of the Appalachian system, whereas the southern province is characterized by northwesterly trends. The southern province appears to be a continuation of the Ouachita system, which has been traced by other means beneath the Gulf Coastal Plain to within 60 miles of the subsurface extension of the Appalachian system in Mississippi, where the two systems also appear to be discordant. Depth estimates from Florida aeromagnetic data suggest that faulting may be a factor in the profound downwarp and accumulation of sediments in the southern province. The zone of intrusive rocks inferred from the magnetic map checks well with the location of the area of crystalline rocks previously delineated by P. L. Applin on the basis of well samples.

Aerial radiological surveys

Aerial radioactivity measurements, made on behalf of the Atomic Energy Commission within a radius of 50 miles of several nuclear facilities to provide a datum to which changes in background radioactivity can be compared, show a good correlation with the local geology. For example, preliminary study of the radioactivity over Long Island, which ranges from 500 to 700 counts per second, indicates a difference of about 100 counts per second in the radioactivity of different glacial units. In the Fort Belvoir area, in Maryland and Virginia, highs and lows on radiation profiles over Cretaceous strata correspond to the location of outcrop bands of marine and nonmarine sediments, respectively; both are less radioactive than the Piedmont rocks. In the Georgia-South Carolina area, also (Schmidt, 1959; Guillou and Schmidt, Art. 55), the coastal plain sediments are less radioactive than the rocks of the Piedmont, and the Cretaceous and Eocene rocks, which are apparently derived in part from nearby granite and gneiss, are more radioactive than the younger coastal plain strata. Flood-plains of streams heading in the Piedmont and older coastal plain formations are more radioactive than those of streams that drain areas underlain by post-Eocene sediments.

Paleontologic and stratigraphic studies

In Florida and Georgia Schopf (1959b) has extracted a rich assemblage of small microfossils from well samples of dark fissile shales of Ordovician and Silurian age. They include chitinozoans, hystrichosphaerids, and numerous sporelike forms, some of which may represent chitinous envelopes of testacean protozoans. Pyrite and abundant carbonaceous material indicate an environment of restricted circulation, and the microfaunal assemblage probably represents a sargassoid biocoenosis.

An exhaustive report on Cenozoic echinoids of the eastern United States by Cooke (1959) describes 144 species within 60 genera. Nearly all the species are restricted to single time units, and hence form good horizon markers.

Fossils indicate that the late Oligocene sea was cool in South Carolina (Malde, 1959a), whereas it was of a tropical nature in central Georgia (E. R. Applin, Art. 90).

In New York, the landward but non-outcropping edge of a previously unknown glauconitic formation has been recognized by Ruth Todd and N. M. Perlmutter from shallow wells along the barrier beach on the south side of Long Island. Foraminifera in this unit seem to be related to Cretaceous assemblages known in the New Jersey Coastal Plain and in the walls of a submarine canyon at the outer edge of Georges Bank, east of Cape Cod. In New Jersey progressive changes in strike of successively younger formations, together with other evidence, indicate that differential uplift and subsidence of the Coastal Plain took place during much of its history (Minard and Owens, Art. 82).

Altschuler and Young (Art. 89) have concluded that the sand mantle in the higher area of eastern Hillsborough and western Polk Counties, Florida, is principally a residual sand plain formed by lateritic weathering of the Pliocene Bone Valley formation, rather than a succession of Pleistocene marine terraces.

EASTERN PLATEAUS

Interpretation of geophysical surveys

The Eastern Plateaus are underlain by nearly flat-lying Paleozoic rocks, which are gently folded in the Cincinnati and Nashville domes, the Allegheny synclinorium, and the Eastern Interior Basin.

Geophysical studies in this region have thrown much light on regional geologic structure and on the composition of basement rocks. Interpretation of aeromagnetic profiles (King and Zietz, Art. 88) shows that the wedge of sediments east of the Cincinnati arch is 8,000 to 10,000 feet thick in eastern Kentucky and Tennessee and thickens northeastward to more than 17,000 feet in West Virginia, Pennsylvania, and New York. In the region as a whole the magnetic anomalies generally trend northeastward, approximately parallel to Appalachian structures. The anomaly pattern indicates sharp contrasts in the crystalline basement rocks, and in some areas it appears possible to define characteristics of the Precambrian basement. Near the axis of the Cincinnati arch, for example, where the Paleozoic rocks are thin, the magnetic data indicate the presence of about 15,000 feet of sedimentary rocks, probably in large part Precambrian.

Aerial radiological monitoring in the vicinity of nuclear facilities, undertaken on behalf of the Atomic Energy Commission, shows a well-defined radioactivity anomaly parallel to the Pine Mountain fault in the Cumberland Plateau; the general radioactivity ranges from 300 to 800 cps. Elsewhere on the plateau radioactivity units are less distinct. Used in conjunction with aeromagnetic measurements, these data may aid in the interpretation of bedrock geology.

Geologic mapping in western Kentucky

Mapping in the fluorspar district of western Kentucky by R. D. Trace has delineated several previously unmapped faults of the northeast-trending fault system, which controls the fluorspar deposition. Movement along these faults appears to have been vertical, for they do not offset older dikes. By detailed study of drill logs, it has been found that the total thickness of the Osage series and the Warsaw, Salem, and Saint Louis formations is 1,500 feet, and that the formations in the Chester series are more uniform in thickness and lithology than previously thought. Much of the reported variation was due to mistakes in correlation across unrecognized small faults.

Stratigraphy of Upper Devonian rocks in western New York

Detailed mapping and correlation of key beds in the cyclically deposited Upper Devonian rocks in western New York show that the redefined Genesee formation is an eastward-coarsening wedge of marine rocks which thicken from 9½ feet of dark shale and thin-bedded *Styliolina*-bearing limestone at Lake Erie to more than 900 feet of intercalated sandstone, siltstone, and black and gray shale near Ithaca (de Witt and Colton, 1959b). The Genesee thickens most abruptly in the 30 miles between Penn Yan and Ithaca, where the Sherburne flagstone member and the Ithaca member tongue in from the east. Previous workers failed to recognize the extent of the tongues west of Ithaca and miscorrelated the Ithaca member with younger rocks in the Sonyea formation. Conodont studies by Hass (1959) suggest that the Geneseo shale member, the basal black shale facies of the Genesee formation, is predominantly Middle Devonian in age, and that the boundary between the Middle and Upper Devonian rocks in the Finger Lakes district is near the base of the *Orbiculiodea lodiensis* zone about 10 feet below the top of the Geneseo. Correlation of many of the members of the Genesee formation was corroborated by Hass' condont studies.

Quaternary geology in Pennsylvania and the Ohio Valley

Reconnaissance mapping of the Quaternary geology and soils of the Elmira, New York-Williamsport, Pennsylvania area by C. S. Denny in company with W. H. Lyford, soil scientist with the U.S. Soil Conservation Service, has shown that the soils on Wisconsin drift do not show the effects of deep weathering and that differences in them are related primarily to lithologic differences in the drift. Drift of pre-Wisconsin age, however, is strongly weathered to depths of more than 30 feet, and supports Red Yellow Podzolic soils, which are not found on adjacent weakly weathered Wisconsin drift or on Recent colluvium. The weathered drift contains considerably more kaolinite than the unweathered drift, from which it also differs in containing a little gibbsite. Colluvial deposits within the area underlain by Wisconsin drift are thicker and more extensive south of the Valley Heads moraine than north of it, suggesting that many of these deposits were formed not later than the building of this moraine. Evidently the erosive processes that form volluvium have not been as active in post-Valley Heads time as they were in early Wisconsin time.

Four Quaternary loess deposits have been mapped along the Ohio River between its mouth and Louisville, Kentucky (Ray, Art. 92). The oldest, of Kansan age, is overlain by the Loveland loess, of Illinoian age; the two younger are of Wisconsin age. Each was derived from glacial drift deposited about Louisville, and each in turn was the source of alluviation downstream. Remnants of terraces formed during the last two periods of aggradation can still be observed along the valley. Petrographic studies of loess formation in the Ohio Valley by P. D. Blackmon confirm earlier findings that stratigraphic correlations can be made by size analysis and clay mineral composition.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY

Results of recent geophysical, geologic, and geochronologic studies in the Shield area and upper Mississippi Valley are described in the following paragraphs. Additional information on zinc-lead and iron deposits is given on pages A1 and A2.

Remanent magnetization in the Lake Superior region

Geophysical studies by Gordon Bath in northern Minnesota, done in cooperation with the Minnesota Geological Survey, and in adjacent parts of Wisconsin have explained many unusual and unexpected magnetic anomalies. Contrary to previous theory, the amplitude of the anomalies is not entirely controlled by the induced magnetization of the magnetite in the rocks. For example, a strong remanent magnetization is required to explain the magnetic anomaly over the Keweenawan lava flows (Art. 93). In addition, there are strong lows over magnetite-rich formations of the East Mesabi district and pronounced highs over magnetite-poor formations of the Vermilion district, which indicate that the rocks show the effects of demagnetization and remanent magnetization, as well as of the induced magnetization of the magnetite. The basic igneous rocks of the Duluth gabbro yield magnetic lows explainable only by a remanent magnetization at right angles to the induced magnetization.

Interpretation of geophysical data in central Wisconsin

Aerial magnetic and radioactivity data, interpreted by J. W. Allingham and R. G. Bates, helped in mapping the geology of an area of about 250 square miles near Wausau, Wisconsin. The extensive cover of residual soil and glacial drift is there underlain by volcanic and sedimentary Precambrian rocks, which have been metamorphosed to the greenschist and amphibolite facies and intruded by various kinds of igneous rocks. Areas of granite, diorite, hornblende gabbro, and diabase have been delineated by their distinctive magnetic patterns, and an area of syenite has been outlined from radioactivity profiles. Pendants of quartzite and chlorite schist that are remnants of a large fold have been defined by an arcuate pattern of magnetic anomalies related to skarn and diorite.

Geologic studies in northern Michigan and Wisconsin

In the copper-bearing Keweenaw Peninsula of Michigan, the rate of thickening of the lava series toward the center of the Superior structural basin as determined by W. S. White indicates that the lavas need not have extended much beyond their present areal limits. It is therefore unnecessary to suppose that a great thickness of lavas beyond these limits was eroded away (White, 1960b). Filling of the basin with vast horizontal lava sheets nearly kept pace with subsidence, but there were pauses in the influx of lavas, during which continued subsidence locally reversed slopes, so that streams carried sand and gravel into the basin to form clastic deposits interbedded with lavas. Zoning of amygdule minerals in the lavas of the Keweenaw Peninsula crosses stratigraphic units and was probably controlled by temperature. The similarity in mineralogy of the flow tops throughout the Lake Superior region indicates that the mineral zones are of regional extent (Stoiber and Davidson, 1959).

In the Iron River-Crystal Falls district, Michigan, studied in cooperation with the Michigan Geological Survey Division, a new group of formations of middle Precambrian age was established, a succession approximately 6,500 feet thick was defined, and several reliable stratigraphic markers were recognized. The major structure is a triangular basin. The apical areas of this basin are faulted and intricately folded, and a typical system of westward-plunging folds modifies the southerly trend of the east limb of the basin (James and others, 1960).

The Lake Mary quadrangle in Michigan, also investigated in cooperation with the Michigan Geological Survey Division, is underlain by lower and middle Precambrian metavolcanic rocks, dolomite, slate, and iron formation, cut by dikes and sills of metagabbro (Bayley, 1959a). One of the sills, which is about a mile thick and is now nearly vertical, has been shown by Bayley to have been originally a differentiated sheet, with an ultramafic zone near the base and a granophyric zone near the top; the original pyrogenic minerals, however, have been almost entirely altered to metamorphic minerals of the greenschist facies (Bayley, 1959c). The regional metamorphic grade rises to a maximum in the southern part of the area around a small syntectonic complex of igneous rocks ranging from metagabbro to granite. The major structure is the Holmes Lake anticline, but the rocks are cut by faults that dislocate the isofacies.

Detailed mapping of rocks of middle Precambrian age by C. E. Dutton in Florence County, Wisconsin—done in cooperation with the Wisconsin Geological and Natural History Survey—has shown that strata of late Animikie age near Florence are folded and faulted at the southeast apex of a triangular basin that extends northwestward into Michigan. The sequence of late Animikie along the northeastern flank of the basin is incomplete because the two lowest formations pinch out as a result of nondeposition or truncation. The sequence of late Animikie age along the southwest flank occurs in Wisconsin only in a small syncline in a graben. The area between the graben and the apex of the basin and a similar area southwest of the graben are underlain by uplifted, much less complexly folded strata of older Animikie age extending from the southeast.

Age of some Pleistocene sediments

Several samples of Pleistocene sediments from the upper Mississippi Valley have recently been dated by Meyer Rubin. Snail shells collected by John Frye of the Illinois Geological Survey from loess in Illinois proved to be older than the Farmdale substage, previously found to be about 25,000 years old, and younger than the Sangamon interglacial stage. These and other dates determined by the Survey's C^{14} laboratory have been used by Frye and Willman of the Illinois Survey to revise the chronology of the Wisconsin stage of glaciation.

A sample of wood collected near Gilbert, Minnesota, was found to be 11,330 years old. It is therefore of the same age as the Two Creeks Forest wood, which was covered by the Valders advance in Wisconsin, and it shows that this advance must have extended into the Lake Superior basin. Six samples of wood from the till of Iowan age in Iowa gives ages of more than 30,000 years. These ages differ widely from the 21,000–22,000 year ages of samples of loess in Illinois previously assigned to the Iowan substage and indicate that the loess is probably an advance eolian deposit of the Tazewell substage rather than of the Iowan.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT

Mesozoic stratigraphy of the eastern Gulf Coastal Plain

Data from well samples are being used by Paul and Esther Applin to compile maps on a scale of 1:1,000,000 and cross sections showing the subsurface geology of Mesozoic rocks in parts of Florida, Georgia, Alabama, and Mississippi. During the course of this work, the subsurface contact between the Comanche and Gulf series has been delineated in western Florida; limestone of Trinity (Comanche) age has been identified in Lamar County, Alabama, and rocks of Late Jurassic age in Madison and Rankin Counties, Mississippi, and Washington County, Alabama. Fossils found in Harrison County, Mississippi, make it possible to distinguish beds of Fredericksburg age in the Comanche series; and fossils in the Comanche series in Walthall and Hancock Counties, Mississippi, show that the beds containing them are roughly equivalent to rocks of Trinity age in Florida.

Lithofacies and origin of Tertiary sediments in the coastal plain of southern Texas

The origin and geologic environment of uranium deposits in Tertiary sediments of the central and southern Texas coastal plain have been investigated by Eargle (1959a, b) (see also p. A10). He has found that the Jackson group (Eocene) near its outcrop consists of deltaic and lagoonal deposits, but that these grade down-dip into offshore bar and marine deposits. Deposition was influenced by structural activity, for the sediments grow coarser near faults, thin over positive structural features, and thicken over negative ones.

Buried igneous masses in Missouri and Arkansas

Aeromagnetic mapping shows anomalies in Stoddard County, Missouri, and near Walnut Ridge and Newport, Arkansas, that are ascribed to buried igneous masses, some of which are ridges 3,000 to 6,000 feet below the surface.

OZARK REGION AND EASTERN PLAINS

In addition to the information reported in previous sections on fuels, potash, and nuclear test sites (see p. A7, and A12), recent work in northwestern Arkansas and southeastern New Mexico has contributed to knowledge of regional geologic relations, as follows.

Geology of northwestern Arkansas

Rocks of Ordovician to Early Pennsylvanian age that crop out in the Ozark region of Arkansas have been found to dip and generally thicken southward under a thick cover of Atoka and younger Pennsylvanian rocks in the Arkansas Valley (Frezon and Glick, 1959). The base of the Boone formation (Mississippian) has a regional dip of only about 10 feet per mile in the northern part of Arkansas, but its dip is as much as 500 feet per mile along the northern edge of the Arkansas Valley, where the deepening of the basin was partly a result of faulting. Nearly all the formations of Ordovician to Pennsylvanian age exhibit thickness and facies changes that indicate that while these formations were being deposited the northern and western part of the Ozark region in Arkansas was covered by shallower water, and subsided less, than the southern and eastern part.

In the southeastern part of the Ozone quadrangle in Johnson County, Arkansas, just southwest of the westernmost edge of a large structurally high area in the Ozarks, the Mulberry fault, which separates the Ozark uplift on the north from the downdropped Arkansas Valley on the south, has been found by E. E. Glick, B. R. Haley, and E. A. Merewether to split eastward into a complicated fault system. The rocks dip westward from the structurally high area, and descend 1,000 feet in 5 miles into a basin, illustrating that considerable local structural relief is superimposed on the regional southward dip in the southern Ozark area. The Atoka formation thickens from about 3,500 feet on the north side of the Arkansas Valley to perhaps as much as 20,000 feet on the south side. The northward convergence of individually mapped beds in the northern part of the area suggests that diastems may account in part for the wedge shape of the unit.

Aeromagnetic studies in southeastern Missouri

Allingham (Art. 95) has found that aeromagnetic measurements are a valuable aid in interpreting the geology of Precambrian basement rocks where they are buried by later sediments along the southeastern flank of the Ozark uplift. Not only is it possible to recognize buried topographic features in the basement, including some that are due to faulting, but it is also possible to differentiate granitic rocks, volcanic rocks, and magnetite-rich iron deposits.

Permian stratigraphy in southeastern New Mexico

In the southwestern part of Eddy County, New Mexico, Hayes (1959) has investigated the stratigraphic relations of Permian shelf rocks to those of the Delaware basin. He has found exposures in Last Chance Canyon that clearly display intertonguing between the upper part of the San Andres limestone (Permian) and the sandstone tongue of the Cherry Canyon formation (middle Guadalupe series). These two units unconformably overlie rocks of latest Leonard or earliest Guadalupe age, or both, that are correlated with the lower part of the San Andres of areas on the north and west. In the Big Dog Canyon scarp a few miles west, rocks of Cherry Canyon age are apparently separated from rocks of latest Leonard or earliest Guadalupe age by more than 580 feet of carbonate rocks that are considered equivalent in age to the Brushy Canyon formation (early Guadalupe) of the Delaware basin. The sequence within the San Andres limestone in Big Dog Canyon may therefore represent nearly continuous deposition from latest Leonard or earliest Guadalupe time into Cherry Canyon time.

The San Andres limestone is overlain by the Grayburg formation. The Grayburg and the overlying Queen formation pass laterally into the Goat Seep limestone and are thus of middle Guadalupe age.

NORTHERN ROCKIES AND PLAINS

Preliminary findings of some of the numerous field investigations in progress in the northern Rocky Mountains and plains are described in the following paragraphs. Results of recent work on mineral deposits in this region are described on pages A1–A14, and landslides related to block faulting are described on page A21.

Geology of parts of northeastern Washington and northern Idaho

The Hunters quadrangle, northeastern Washington, straddles the border between miogeosynclinal sediments and eugeosynclinal sediments and volcanics. A. B. Campbell believes that the contact between these two rock assemblages is a high-angle normal fault in an overthrust sheet. The thrusting moved eugeosynclinal rocks eastward over miogeosynclinal rocks. The Northport district, according to R. G. Yates, lies on the boundary between miogeosynclinal rocks of early Paleozoic age and eugeosynclinal rocks of late Paleozoic and Mesozoic age. Cambrian and Ordovician time is represented by two contrasting assemblages of miogeosynclinal rocks, whose adjacency is interpreted to have resulted from large scale horizontal shortening. In the Republic area, M. H. Staatz (Art. 141),

R. L. Parker, J. A. Calkins, and S. J. Muessig have mapped a large graben that cuts metamorphosed sediments and batholithic intrusives of probable Jurassic age. The graben formed in early or middle Tertiary time as the result of collapse and subsidence associated with volcanic activity. In the Mount Spokane quadrangle, rocks formerly thought to be Late Jurassic or Early Cretaceous intrusions have been found by A. E. Weissenborn to be gneisses and schists that are probably metamorphosed correlatives of sediments of the Belt series that lie east of the Purcell trench.

In the Pend Oreille area of Idaho, aeromagnetic data can be used to locate surface and near-surface plutons, such as those at Packsaddle Mountain and Granite Point, according to a preliminary interpretation by E. R. King. The Hope fault divides the area into a northern highly magnetic section and a southern one of low magnetic gradients in which the anomalies due to the plutons stand out sharply.

Stratigraphy of the Belt series in western Montana and adjacent areas

In western Montana, northern Idaho, and northeastern Washington exposures of slightly metamorphosed Precambrian sedimentary rocks, referred to the Belt series, are widespread. The series is as much as 45,000 feet thick. According to C. P. Ross, who has completed a regional study of these rocks, the groups that make up the series can be recognized throughout the region. The groups, named in stratigraphic descending order, are the Missoula, Piegan, Ravalli, and pre-Ravalli groups. They are being subdivided locally into formations and members, but these lesser subdivisions cannot now be correlated from area to area.

Geology of areas in the vicinity of the Idaho batholith

At the northwest margin of the Idaho batholith, Anna Hietanen-Makela has delineated three structural trends, along each of which folding or refolding has occurred; each phase of the deformation was followed by faulting and intrusion. During the geologic mapping of the Yellow Pine quadrangle, Idaho—part of a program to obtain a geologic cross section of the Idaho batholith—B. F. Leonard has found large recumbent folds in highly metamorphosed "Belt" rocks previously thought to be nearly flat lying. The folds generally trend northwest, but locally they are interrupted by others that trend east-northeast. In the Riggins area, Idaho, Hamilton (Art. 103) finds that the metamorphic grade of volcanic and sedimentary rocks increases eastward toward a broad complex of intrusive and metamorphic gneisses that are marginal to the Idaho batholith. Two post-metamorphic, west-directed thrust faults have an aggregate displacement of about 10 miles. In the Leesburg quadrangle, W. H. Nelson has found that rocks of the Belt series were metamorphosed to the biotite grade and locally to the garnet grade of dynamothermal metamorphism during the emplacement of the Idaho batholith. E. T. Ruppel finds that the Lemhi Range, in the southern part of the Leadore quadrangle, is underlain principally by Precambrian and early Paleozoic sedimentary rocks, which have been folded into folds that trend about N. 25° W. These rocks are cut by early high angle faults that trend northwest, by later ones that trend northeast, and by nearly flat overthrust faults of uncertain relations.

Geology of parts of western Montana

In the Sun River Canyon area, M. R. Mudge has found fossils that show that the Devils Glen dolomite is of Late Cambrian age. The Morrison formation (Jurassic) in this area changes in facies along the Sun River from gray and olive drab mudstones and interbedded sandstone and fresh water limestone east of the Gibson dam to red-brown fine- to coarse-grained cross bedded sandstone and interbedded mudstone west of the dam. The two facies are in thrust contact near the dam.

In the Willis quadrangle of southwestern Montana, W. B. Myers has shown that Middle and Upper Cambrian strata overlap a truncated erosion surface on faulted strata of the Belt series—relations that indicate deformation in Precambrian or Early Cambrian time. A similar deformation is inferred for the Highland Mountains by M. R. Klepper and H. W. Smedes, where thick coarse breccias of very limited extent, possibly reflecting block faulting, occupy the stratigraphic position of the Cambrian Flathead or Wolsey formations in that area. Geologic mapping by Myers also indicates that thrust faults in the Willis quadrangle are essentially bedding-plane glide surfaces. They originated during the early stage of folding and were active until folding ceased; consequently they are strongly folded.

In the Livingston-Trail Creek area, A. E. Roberts has found evidence for at least two pulses of thrusting toward the south and southwest. During the early one, an anticline composed of Paleozoic rocks was thrust onto a syncline of Cretaceous rocks. During the later episode, Precambrian rocks were thrust over Cretaceous rocks. In the Maudlow area, Betty Skipp has mapped an imbricate Laramide thrust zone, with throws up to about 1,700 feet, in overturned Paleozoic and Mesozoic beds along the front of the Horseshoe Hills.

According to Zietz (Art. 102), aeromagnetic profiles across a pluton near Three Forks indicate that the pluton is bottomed at a depth of several thousand feet; this strengthens evidence from the mapping of G. D. Robinson which suggests that the pluton was cut off by the nearby Lombard thrust.

Coral zones in Mississippian rocks

W. J. Sando (Art. 100) has recognized five coral zones in the Madison and correlative rocks of Mississippian age in the northern Cordilleran region that are useful in regional correlation. The zones indicate that the Brazer, Mission Canyon, and Charles formations are partly equivalent in age.

Geology of parts of western Wyoming, southeastern Idaho, and northeastern Utah

In the Clark Fork area, Wyoming, W. G. Pierce (Art. 106) has found that the breakaway point of the Heart Mountain detachment fault is near the northeast corner of Yellowstone Park. From this point, horizontal displacement of individual blocks increases southeastward to about 30 miles at the most southeasterly limit, 65 miles way.

The Meridian Ridge or Wyoming anticline, where studied by S. S. Oriel, is a complex structure, rather than a simple anticline as heretofore believed. He found that the Thaynes limestone of Triassic age was earlier mistaken for the Twin Creek limestone of Jurassic age along the east side of the structure as previously mapped, accounting for much of the erroneous closure. Furthermore, the west side of the structure is cut by steeply dipping faults whereas the east side is complicated by numerous local structures which may be subsidiary to a major fault that lies further east and is covered by Tertiary rocks.

In the Green River basin and in Jackson Hole, Wyoming, J. D. Love found proof of pre-Tertiary tilting and erosion. In both areas successively older Cretaceous strata are exposed from east to west, and are overlapped by 5,000 to 15,000 feet of Paleocene strata. Love has also mapped many late Pliocene and Quaternary normal faults, several having displacements of from 10,000 to more than 20,000 feet, and in the Jackson Hole area he has collected Pliocene invertebrates that demonstrate folding of Pliocene or later age. In the vicinity of Bear Lake Valley, Idaho, F. C. Armstrong and E. R. Cressman find that post-Laramide deformation consists of normal faulting and tilting, with only minor folding.

In the Wasatch Mountains of Utah, consistent lead-alpha ages had indicated that the Little Cottonwood stock was Eocene. Recent mapping by M. D. Crittenden, Jr., however, has shown that it is cut by the Charleston thrust, elsewhere known to be of Cretaceous age. The granite mylonite, a product of this thrusting, is cut by normal faults of middle Tertiary age, as well as by the Wasatch fault of probable Pliocene and Pleistocene age.

Geology of the Wind River basin, Wyoming

In the Wind River basin area, W. R. Keefer and J. D. Love have found evidence that during early Tertiary time central Wyoming was invaded by a sea, or occupied by a large lake, in which 2,000 feet of dark gray and black shale was deposited. They have shown also that structures along the margins of the basin began to develop locally in Late Cretaceous time and continued to form through the Paleocene (Keefer, Art. 105). One of the largest and most varied Paleocene mammal faunas known in central Wyoming was found by Keefer in the Shotgun Butte area. Although this collection has not been fully studied, it is known to contain several hundred mammal teeth and abundant shark teeth.

Geologic and geophysical studies in parts of the Black Hills, South Dakota

In the southern part of the Black Hills, G. B. Gott and others have found that mild structural deformation occurred prior to Fall River time (Early Cretaceous); this probably localized the fluvial sandstones in the Lakota formation, and may have been the beginning of the Black Hills uplift. Deposits of fluvial sandstone in both the Lakota and Fall River formations are elongate in a northwestward direction and cross beds dip northwest, suggesting a southeastern source area for most of the sediments of the Inyan Kara group. In the Newcastle area, on the west side of the Black Hills, W. J. Mapel inferred from the orientation of cross beds that the streams that deposited the Cretaceous Lakota formation flowed northward. Throughout the southern Black Hills, solution of nearly 250 feet of calcium sulfate from the Pennsylvanian Minnelusa formation and the subsequent calcium carbonate recementation of collapse breccias began in early Tertiary time and is continuing.

Gravity measurements made by R. M. Hazlewood show gravity highs and lows that trend parallel to the eastern flank of the Black Hills uplift. His data also indicate that a steep gravity gradient extends all the way along the west flank of the Black Hills.

Devonian rocks in eastern Montana and western North Dakota

Widespread subdivisions of the Jefferson and Threeforks formations, both of Devonian age, have been recognized by C. A. Sandberg in eastern Montana and western North Dakota. He has also found that the

Beartooth Butte formation, of Early Devonian age, is more extensive than supposed and may be equivalent to the lower part of the Maywood formation.

Lithofacies and thickness of the Pierre shale in South Dakota

In a comprehensive study of the Cretaceous Pierre shale (see also p. A64 and Art. 205), H. A. Tourtelot, L. G. Schultz, and J. R. Gill have found that along the Missouri River in central South Dakota it consists of clayey rocks with a carbonate-rich unit in the upper part and several thin beds of marlstone in the lower part. In the Black Hills region, it contains little carbonate and more silt and sand. The thickness of the Pierre increases from about 500 feet in southeastern South Dakota to more than 3,000 feet on the southwestern flank of the Black Hills.

Geology of the Bearpaw Mountains, Montana

In the Bearpaw Mountains, W. T. Pecora and B. C. Hearne, Jr. have found that the complexly faulted border zone surrounding the mountains narrows eastward and is characterized by steep normal faults. This zone contains down-faulted blocks of volcanic rocks and Tertiary and Upper Cretaceous formations, which have depressed the surrounding formations. Data on remanent magnetism obtained by K. G. Books indicate that before deformation the volcanic rocks generally dipped northwest in the northern volcanic field and southeast in the southern volcanic field.

Glaciation in the vicinity of Glacier National Park, Montana

East of Glacier Park, G. M. Richmond, R. W. Lemke, and E. Dobrovolny determined the stratigraphic relation between continental glacial deposits and the Alpine-piedmont deposits of Bull Lake and Pinedale age. In the Glacier Park area itself, Richmond (Art. 98) found evidence of three Wisconsin glaciations, two ice advances in Bull Lake time, three in Pinedale time, two in early Recent time, and two in late Recent time.

SOUTHERN ROCKIES AND PLAINS

Geologic field investigations in the Southern Rockies and plains in 1960 yielded important results in the study of Precambrian basement rocks, volcanics of Cenozoic age, and sedimentary rocks of Mesozoic and younger age as described below (see p. A3–A5 and A13 for information on mineral deposits in this region).

Precambrian rocks and structures in the Front Range and Sawatch Range, Colorado

Geologic mapping has recently been started in the Front Range of Colorado to obtain a geologic cross-section of the range at about mid-length, and a longitudinal section of the east-central foothills. This work has already shown, among other things, that the oldest Precambrian rocks, a thick series of metasediments which T. S. Lovering and E. N. Goddard had previously grouped mainly in the Idaho Springs and Swandyke formations, can be subdivided into several mappable units of wide areal extent (see Koschmann and Bergendahl, Art. 113). J. D. Wells and D. M. Sheridan have found that the quartzite at Coal Creek, previously regarded by Lovering and Goddard as younger than the biotite gneisses of the Idaho Springs formation, grades into that gneiss. Sims and others (1959) showed that the rocks in the central Front Range were deformed during at least two periods in Precambrian time. Many faults, including the breccia reefs that were previously thought to be of Laramide age, originated in Precambrian time according to evidence presented by P. K. Sims and G. R. Scott.

Ogden Tweto and R. C. Pearson, on the basis of comprehensive work in the northern Sawatch Range, have delineated an elongate swarm of metamorphosed lamprophyre dikes within a great Precambrian shear zone. These dikes record almost the latest Precambrian event in the region, for they are younger than the plutonic granites and the regional metamorphism, yet they themselves are metamorphosed, approximately to the amphibolite facies (Pearson, 1959).

An important outgrowth of studies of the Precambrian in the Front Range and Sawatch Range is the recognition that the Colorado Mineral Belt, defined by Laramide intrusive rocks and ore deposits, is coextensive with and localized by a zone of intense Precambrian shearing (Tweto and Sims, Art. 4).

Geology of volcanic terranes in Colorado and New Mexico

In studying the classic volcanic terrane of the San Juan Mountains, Colo., Luedke and Burbank (Art. 7) mapped several ring-fracture zones, associated with ring dikes related to a late intrusion within the well-known Silverton caldera in the western San Juans. Steven and Ratté (Art. 8) discovered a major caldera near Creede, in the central San Juans, and related its subsidence to voluminous ash flow eruptions. The veins in the Creede district were deposited on the north margin of the caldera along faults extending outward from it; many of these faults were active throughout the subsidence of the caldera, but no significant mineralization took place until after the last major period of fault movement (see p. A4). Mapping in the Spanish Peaks area of south-central Colorado by Ross B. Johnson has shown that the radial dikes around West Spanish Peak and Dike Mountain occupy a joint complex that resulted mainly from intermittent orogenic stresses caused by the formation of the LaVeta syncline, which occurred before the magma was emplaced. Earlier workers generally attributed the radial fissuring to doming of the sedimentary rocks by the emplacement of the stocks. Studies by C. S. Ross, R. L. Smith, and R. A. Bailey in the Valles Mountains area, New Mexico, have led to the recognition of zones and zonal variations in ash flow tuffs that should be widely applicable.

Ceology of North Park, Colorado

In North Park, a structural and topographic basin between the Park Range and Front Range, it has been found that the widespread Coalmont formation is of Paleocene and Eocene age (Hail and Leopold, Art. 117) and that the North Park formation is probably of late Miocene age (Hail and Lewis, Art. 116). Geologic mapping in the basin by D. M. Kinney and W. J. Hail, Jr. indicates that folding and high-angle thrusting related to the Laramide orogeny began before deposition of the Coalmont formation and continued throughout its deposition. A conspicuous unconformity in the Coalmont between the Paleocene and the Eocene shows that marked uplift took place locally along the basin margins.

Age of deformation in the Raton basin, Colorado

Johnson (1960) and others have concluded, from the results of geologic mapping, that the Laramide Revolution began in the Raton basin of south-central Colorado with epeirogenic movements in late Montana (Late Cretaceous) time. These epeirogenic movements were followed by at least seven orogenic episodes of decreasing magnitude, which extended into Miocene time, and by normal faulting in late Tertiary.

COLORADO PLATEAU

Most of the geologic studies on the Colorado Plateau have been undertaken to aid the search for uranium and fuels (see p. A9, A11, and A13), but they are also making important contributions to an understanding of the regional geology and history of the area. Some of the new findings are summarized below.

History of salt anticlines in the Paradox basin

Studies of the salt anticlines in Paradox Valley, Gypsum Valley, Fisher Valley and other areas by D. P. Elston, E. R. Landis and E. M. Shoemaker show that the salt cores were formed in Late Pennsylvanian and Permian time and continued to grow from Triassic to Early Cretaceous time (Art. 118). Subsequent solution of salt and redistribution of salt by plastic flow has resulted in the collapse of Mesozoic rocks deposited over the salt cores; this movement has continued through late Pleistocene time.

In the eastern part of the Paradox basin, the distribution of subsurface formations suggests that the northwesterly trend of the salt anticlines was inherited from structures formed before the deposition of salt of the Paradox member of the Hermosa formation in Middle Pennsylvanian time. This conclusion is reinforced by the geophysical findings of H. R. Joesting and P. E. Byerly (Byerly and Joesting, 1959; Joesting and Case, Art. 114). Magnetic and/or gravity anomalies are associated with all larger uplifts, basins, salt anticlines, and laccoliths of the central Colorado Plateau. Regional anomalies, associated with the large salt anticlines and with at least some of the laccoliths, relate to structures in the Precambrian basement rocks, and perhaps to structures in pre-Mississippian formations. In many areas, however, the configuration of the surface of the basement is not reflected in post-Mississippian rocks.

Structure in the vicinity of the Carrizo Mountains

A discordance in structure in the Carrizo Mountains has been brought out through the subsurface studies of J. D. Strobell. Well data indicate that an old land mass in the Carrizo Mountains area was lapped by Cambrian sandstone and overstepped by limestones of the Devonian Elbert and Ouray formations. On the Precambrian highland just west of the Carrizos the Mississippian Leadville and Redwall limestones also lap out on markedly thinned Devonian beds. The basal Pennsylvanian Molas formation extends across the eroded complex. Accumulations of oil and notably high concentrations of helium in nitrogenous natural gas occur below the relatively impermeable Molas formation in solution cavities near the top of the Leadville and Redwall limestones and in porous crystalline zones in the lower part of this limestone.

Stratigraphic and paleontologic studies of Mesozoic rocks

The results of a stratigraphic study of the San Rafael group by J. C. Wright show that the connection between the shallow Utah basin of deposition and the open ocean to the west was restricted in Jurassic time. This basin was probably saline, as indicated by the meagre fauna and prevailing red color of the San Rafael group in the basin as well as by the saline precipitates that it contains. In eastern Utah substantial but locally erratic erosion of the underlying Navajo sandstone took place not only on salt structures but also in other areas.

R. A. Scott reports that collections from the Chinle formation of five localities widely separated on the Colorado Plateau have yielded rich assemblages of pollen and spores. Pollen of *Ephedra* were identified, and also pollen and spores comparable to those in the European Keuper.

In the Uinta Basin of the northeastern part of the Colorado Plateau, Zapp and Cobban (Art. 112) have been able to map and date the landward extent of marine wedges and the seaward extent of non-marine wedges for five major transgressive cycles in rocks of post-Eagle (Cretaceous) age.

BASIN AND RANGE PROVINCE

Noteworthy advances in our understanding of the geology of the Basin and Range province have been made recently in regard to: (a) thrust faults in Nevada; (b) geology of the Mojave Desert; (c) geology of the Sierra Diablo area, Texas; (d) dating of strata; (e) crustal structure and block faulting; and (f) Quaternary history (see pages A2–A8 for new information on mineral deposits in this region).

Thrust faults in Nevada

In the Osgood Mountains, P. E. Hotz and Ronald Willden have found rocks transitional between the eugeosynclinal clastic and volcanic facies typical of western Nevada and the miogeosynclinal carbonate facies typical of eastern Nevada. Since the Osgood Mountains are 90 miles west of the eastern trace of the Roberts Mountains thrust, and since the overriding plate of the Roberts Mountains thrust contains rocks of the eugeosynclinal facies along its eastern margin, those rocks must have originated west of the Osgood Mountains, and have been moved more than 90 miles eastward to reach their present position. In the northern part of the Shoshone Range, Gilluly (Art. 119) and others have found that the Roberts Mountains thrust is folded into a tight overturn and is cut by younger thrusts.

In the Snake Range, Nevada, mapping of complex structures by D. H. Whitebread has shown that the thrust faults consistently show younger rocks thrust over older rocks. Within the upper plates of the thrust faults are numerous northward-trending faults with predominantly strike-slip movement. In the Schell Creek Range, Drewes found that the Paleozoic rocks east of Connors Pass are thrust on several bedding-plane faults that removed tens to thousands of feet of an otherwise normal sequence (Art. 122).

Cenozoic rocks and structures in the western Mojave Desert, California

Geologic mapping by T. W. Dibblee, Jr., G. I. Smith, and others, and concurrent geophysical surveys by D. R. Mabey, undertaken as a part of borate investigations (see p. A7), have shown that in the western Mojave Desert the surface alluvium of some basins conceals extensive and thick accumulations of Cenozoic sedimentary and volcanic rocks. Whereas actual exposures of the Tertiary and Pleistocene rocks make up only about 10 percent of the area, about 30 percent more of the area is probably underlain by Tertiary and Pleistocene fill. The greatest thickness of fill, about 10,000 feet, is in basins that are near the Garlock and San Andreas faults. Structure within the concealed fill is largely unknown; little of it has been explored by test drilling. The mapping of exposed Cenozoic rocks has shown, however, that they are much faulted and that they are sharply folded in many places, particularly near the steep northwest-trending faults that characterize the Mojave Desert.

Geology of the Sierra Diablo, Texas

Structures of Basin and Range type extend southeastward into the northwestern trans-Pecos area of Texas, where a long intermontane depression, the Salt Basin, is bordered on its eastern and western sides by fault-block ranges. The Guadalupe Mountains, one of the ranges on the east, was previously described by P. B. King, and he is now preparing a report on the Sierra Diablo, a range on the west. The Sierro Diablo fault block had a considerable prior history as a positive area, dating back to a period of folding and faulting near the close of Pennsylvanian time. Deformed Pennsylvanian and older rocks are overlain by a mass of Permian carbonate rocks of Wolfcamp and Leonard age several thousand feet thick which compose the main part of the range. They were formed on a submarine platform at the southwestern edge of the Delaware basin, and the Leonard series at the margin of the platform is a complex of bank, reef, and fore-reef deposits. Knowledge of the Wolfcamp and Leonard series of the Sierra Diablo supplements knowledge of the Guadalupe series in the nearby Guadalupe Mountains, making the composite sequence of the two areas one of the standards of reference for the marine Permian in North America.

New information on the age of strata

Geologic mapping by H. R. Cornwall and F. J. Kleinhampl in the southern Grapevine Mountains of Nevada indicates that olenellid-bearing shales of late Early Cambrian age, previously discovered by J. F. McAllister, belong to the Johnnie formation. This is the lowest known occurrence of fossils in the stratigraphic column in the Great Basin.

Research on Great Basin graptolites by R. J. Ross, Jr., and W. B. Berry indicates that the entire span of the Ordovician is present in the Great Basin in both eugeosynclinal and miogeosynclinal facies. These studies make possible fairly precise correlations between the two facies, and also with graptolite-bearing rocks of New York, Texas, Australia, and Great Britain. J. G. Moore (Art. 131) has found from a review of all fossil evidence that the metavolcanic rocks in roof pendants of intrusive bodies related to the Sierra Nevada batholith in western Nevada are of Late Triassic and Early Jurassic age.

Crustal structure and block faulting

Gravity studies (see Mabey, Art. 130) in the Basin and Range province have revealed an inverse correlation between the Bouguer anomaly values and regional topography, suggesting that regional isostatic compensation exists throughout the region. The gravity data indicate that several basins are underlain by over two miles of Cenozoic rock, and the pre-Tertiary rock surface under some of these basins is as much as two miles below sea level.

From an analysis of the block faulting that characterizes the Basin and Range province, Moore has found that blocks tend to be tilted toward regional topographic highs, and that many of the major range-front faults are arcuate in plan, concave toward the down-thrown block (Art. 188; see also p. A58).

Tiltmeter observations by Greene and Hunt in the Death Valley area indicate that tilting is going on there at the present time (Art. 124). The amount and direction of tilting differs from one station to another, and the rate of tilting at a given station varies from time to time.

Geophysical studies along the eastern front of the Sierra Nevada suggest that Mono Basin and Long Valley are volcano-tectonic depressions (Pakiser and others, 1960). Pakiser (1960a; see also Art. 189) has suggested that volcanic rocks in this region were erupted from regions of relative tension or stress relief in offsets of major left-lateral *en echelon* shear zones.

Quaternary history

From a study of ancient soils and other surficial deposits, R. B. Morrison believes it possible to correlate the later Quaternary stratigraphic units of the Carson Desert with those of the Bonneville Basin, Rocky Mountains, and Sierra Nevada. His tentative correlations confirm earlier suggestions that Lakes Lahontan and Bonneville fluctuated synchronously, and that both lakes were high when the glaciers were extensive in the Sierra Nevada and the Rocky Mountains. The intricate stratigraphic record related to the fluctuations of Lake Lahontan not only provides evidence on which to base a detailed history of the Carson Desert, but also gives indirect evidence of glacial oscillations not yet recognized in the mountains.

In the Little Cottonwood area, Utah, G. M. Richmond and R. B. Morrison determined by detailed stratigraphic mapping of the Quaternary deposits that there were five lake cycles of Lake Bonneville, with maxima (earliest to youngest) at about 5100, 5135, 4770, 4470 and 4410 feet above sea level.

COLUMBIA PLATEAU AND SNAKE RIVER PLAINS

Current detailed mapping in the Columbia Plateau and Snake River Plains is centered in three areas: the John Day country in north-central Oregon, north-central Nevada, and the Snake River Plain of southern Idaho.

Geology of parts of John Day area, Oregon

In the John Day area, T. P. Thayer finds two generations of layering in a gabbro-peridotite complex that contains chromite deposits, and believes that this layering resulted from magmatic deformation of semi-solid rocks during their emplacement, which took place in Early and Middle Triassic time. Fifty thousand feet of graywacke and volcanic rocks deposited in this area in late Triassic time show major intraformational unconformities, abrupt facies changes, and local thickening, all of which indicate contemporaneous deformation (Thayer and Brown, Art. 139). Metamorphism of these rocks to zeolitic facies, and locally to actinolite-albite facies, has been related to intrusion of granodiorite and related rocks (accompanied by gold mineralization) in Late Cretaceous time.

Fischer and Wilcox (Art. 140) report that the beds of the John Day formation near Monument, Oreg. were largely wind-laid on a subaerial surface of moderate relief. Flows of Columbia River basalt subsequently filled depressions on the surface of the John Day formation, and eventually blanketed the whole region. The youngest of these flows differ from the older ones in texture and in mineral and chemical composition. In Lake County, Oregon, G. W. Walker (Art. 138) has mapped volcanic rock formations that are similar to those of Central Oregon in general stratigraphy, and contain a related vertebrate fauna of Miocene age.

Petrology and remanent magnetism of Snake River lavas

Powers (Art. 137) has found that basaltic rocks of the Snake River valley in southern Idaho differ from other basalts in the northwestern United States in their low content of silica compared to total iron and magnesia, and that some basalt-like rocks are alkalic (Art. 136).

Measurement of remanent magnetism by A. V. Cox on a suite of 800 samples from the basaltic lavas shows that, regardless of differences in mineralogy, the magnetic polarity of basalt of late Pleistocene and Recent age is north-seeking, whereas the polarity of basalt of middle and early Pleistocene age is south-seeking. Moreover, within each of these groups, smaller differences in directions of magnetization can be used to correlate isolated outcrops of individual flows.

Structure and history of the western Snake River plain

Malde (1959b) has shown that the northwest-trending reach of the Snake River Plain in southwestern Idaho developed by major subsidence along faults that cross the trend of Basin and Range faulting. During subsidence of this graben, clastic sediments and subordinate amounts of interbedded basaltic lava and siliceous volcanic ash, which total at least a mile in thickness, were deposited intermittently from early Pliocene to Recent time. Pliocene and lower Pleistocene deposits fill broad basins, whereas the middle Pleistocene and younger deposits are confined to narrow ancient canyons nearly congruent with the present canyon of the Snake River. Malde (Art. 135) relates the youngest deposits to the overflow of Lake Bonneville into the Snake River.

The graben of the western Snake River Plain in Idaho is a region of high gravity in which three large positive anomalies are arranged *en echelon* parallel to the regional northwesterly structural trend (Pakiser, 1960b). Simple Bouguer values of about −70 mgals (milligals) at the gravity highs, by comparison with values of about −125 mgals at the basin borders, are interpreted by Baldwin and Hill (1960) to indicate a buried section of basaltic lava somewhere between the limits 8½ to 24 km in thickness.

A clastic deposit several thousand feet thick in the western Snake River Plain, dated as late Pliocene and early Pleistocene, contains a very large fresh-water molluscan fauna in which D. W. Taylor recognizes 109 species, many of which are new. In degree of endemism, in the variety of species and genera, and in the great variety of individual forms, this fauna is similar to that now living in Lake Ohrid, Yugoslavia, and in Lakes Tanganyika and Nyassa, Africa. It is also similar in these respects to the fossil faunas from the former Pontian, Dacian, and Levantine basins of southeastern Europe.

Aeroradioactivity in the vicinity of the National Reactor Test Station area, Idaho

According to R. G. Bates, aerial radiological surveys (ARMS program) in the vicinity of the National Reactor Test Station area show that the highest natural aeroradioactivity levels, 1,000 to 1,900 cps (counts per second), are found in or near areas of rhyolite and related rocks along the northwest and southeast boundaries of the Snake River Plain and in three areas within the plain. A basaltic lava flow southwest of Idaho Falls has a uniformly low radioactivity of 300 to 400 cps. The aeroradioactivity of aa lava is generally about 50 to 150 cps higher than that of pahoehoe lava, perhaps because the aa has a greater surface area per unit volume, and therefore has a larger effective gamma emitting surface than the pahoehoe. The highest aeroradioactivity levels, up to 1,100 cps, over basaltic lava flows were those recorded over serrate flows in the northeast corner of the Craters of the Moon National Monument.

Cenozoic volcanic rocks and structure in north-central Nevada

In north-central Nevada, R. R. Coats has distinguished several formations of siliceous volcanic rocks alternating with formations of basaltic lavas. Some of the rocks are mineralized with gold, and all are broken by block faults structurally allied with the Basin and Range province. Fossil mammals, mollusks, leaves, and diatoms date the gold mineralization as late Miocene and the subsequent block faulting as latest Miocene or earliest Pliocene.

PACIFIC COAST REGION

Geologic investigations in the Pacific Coast region are grouped for discussion into the following categories: (a) the Sierra Nevada batholith, (b) western foothills metamorphic belt, (c) the Cascade Range, (d) Klamath Mountains and the Coast Ranges of northern California, and (e) major sedimentary basins.

Geology of the Sierra Nevada batholith

The principal objectives of the work in the Sierra Nevada, part of which is being done in cooperation with the State of California, are to determine the spatial and temporal relations and the structure, composition, and mode of emplacement of the plutons that constitute the Sierra Nevada batholith; the stratigraphy and structure of the associated Paleozoic and Mesozoic strata; and the factors that controlled the localization of deposits of tungsten, copper, and gold that characterize the range. The first phase of this investigation is to prepare a reliable geologic map of a strip about 85 miles wide across the central part of the range. This map is being synthesized from all available mapping but it is based mainly on large-scale geologic mapping of critical areas and reconnaissance mapping of intervening areas by P. C. Bateman, L. D. Clark, C. D. Rinehart, D. C. Ross, and others. This mapping, supplemented by stratigraphic and paleontologic studies (Rinehart and others, 1959), shows that the top directions of strata of Paleozoic and Mesozoic age, which form the wall rock and roof pendants, are toward the central part of the range, indicating that the batholith was emplaced along the axial part of a synclinorium. New data confirm and extend certain earlier concepts, namely that the Sierra Nevada batholith is composed of many discrete plutons of granitic rock, which were in general emplaced successively from west to east and show an eastward increase in silica and potassium content. Mapping and petrographic studies by J. G. Moore and P. C. Bateman indicate that most of the individual plutons are concentrically zoned and that quartz and K-feldspar increase toward the core. In the Mount Pinchot quadrangle a swarm of lamprophyric dikes mapped by Moore cuts some of the plutons and in places is cut by others, a fact that helps determine the relative ages of the plutons.

Structure and Jurassic fauna of the western foothills metamorphic belt of the Sierra Nevada

In the western foothills metamorphic belt, L. D. Clark (1960; see also Art. 148) has identified a major system of steeply dipping faults and recognized two distinct stages of deformation. The foothills fault system, which trends northwestward and has been traced for about 200 miles, is a zone of shearing thousands of feet wide; displacement may be measurable in miles.

R. W. Imlay has found that Late Jurassic faunas in this area have a strong boreal aspect, and that they also have affinities with Mexican and Cuban faunas. The Late Jurassic seas in California must therefore have been connected freely northward with Alaska and southward with the Tethyan region.

Igneous rocks of the Cascade Range

As a part of the cooperative program to prepare a State Geologic Map of Oregon, Peck's mapping in the Cascade Range has established the stratigraphic sequence of 15,000 feet of Cenozoic volcanic rocks, ranging in composition from rhyodacite to olivine basalt, and the relations of the lower part of this sequence to the marine Tertiary strata that interfinger with it from the west (Peck, 1960). He has also shown that these volcanic rocks were extruded from vents alined in northward-trending belts, which in general shifted progressively eastward with time (Peck, Art. 144).

In the Holden quadrangle, in the northern Cascade Mountains of Washington, Cater has found that the post-Eocene Cloudy Pass batholith reached an exceptionally high level in the earth's crust. In so doing it developed chilled porphyritic borders and gave rise to hypabyssal porphyry plugs, intrusive breccias, and a volcanic neck (Art. 213).

Stratigraphy and structure of the Klamath Mountains and Coast Ranges, northern California

In the southern part of the Klamath Mountains, geologic mapping of the Weaverville quadrangle, done by Irwin (Art. 147) in cooperation with the State of California, indicates that a belt of metamorphic rocks in that area has a synclinorial structure, and that the Abrams mica schist is probably younger than the Salmon hornblende schist, rather than older as thought by earlier workers.

In the Coast Ranges of northern California geologic mapping has been hampered by lack of fossils and of distinct lithologic units in the thick and structurally complex sequence of Upper Jurassic to Upper Cretaceous graywacke that constitutes much of the terane. The use of stain techniques (Bailey and Stevens, 1960) to determine the distribution of the feldspar content of these rocks may prove to be the clue needed to unravel this geology. Results to date indicate that the Upper Jurassic to Upper Cretaceous rocks on the west side of the Sacramento Valley increase in K-feldspar content with decreasing age, whereas the rocks of the Franciscan formation generally contain no K-feldspar (Bailey and Irwin, 1959).

Geology of major sedimentary basins

In the Los Angeles basin surface and subsurface mapping by J. E. Schoellhamer, A. O. Woodford, J. G. Vedder, R. F. Yerkes, D. L. Durham, T. H. McCulloh, and P. J. Smith, when integrated with the results of density determinations on more than 2,000 samples, made it possible to construct a compartmentalized lithodensity model of the basin. A gravity map, prepared by subtracting the gravitational effects shown by this model from the Bouguer anomaly values, indicates a steep northeastward-sloping residual regional gravity gradient, which is ascribed to landward thickening of the crust (McCulloh, Art. 150).

The position of the boundary between Lower and Upper Cretaceous rocks on the west side of the Sacramento Valley was clarified recently by Brown and Rich (Art. 149) when they recognized an extensive zone of Upper Cretaceous slump deposits that contain blocks with Lower Cretaceous fossils.

In the central part of the Oregon Coast Range basin, P. D. Snavely, Jr. has tentatively concluded from his study of the sedimentary structures and the distribution of lithofacies in the middle Eocene Tyee formation that these rhythmically bedded sandstones were deposited by turbidity currents flowing along the axis of a eugeosyncline about parallel to the present range. In the Juan de Fuca basin and on the northern slopes of the Olympic Mountains, geologic mapping and stratigraphic studies by Brown and others (1960) together with studies of Foraminifera by W. W. Rau, established the stratigraphic sequence of more than 30,000 feet of marine sedimentary and volcanic rocks of early Eocene to middle Miocene age. H. D. Gower has mapped a heretofore unrecognized major structural feature, the northwestward-trending Calawah River fault zone, in the Pysht quadrangle, Washington. He believes that this fault has a left-lateral displacement measured in tens of miles.

Gravity studies by D. J. Stuart in western Washington show a close correlation between gravity highs and thick sequences of Eocene volcanic rocks. In west-central Oregon, R. W. Bromery and P. D. Snavely have inferred from correlation of surface geology with offsets of aeromagnetic patterns, that a fault with a left-lateral separation of about 3 miles extends from the town of Siletz eastward across the poorly exposed rocks in the central part of the Oregon Coast Ranges.

ALASKA

Our understanding of the geology of Alaska is still at an early stage. Large parts of the State have not been mapped at all and our geologic maps of other large parts are not up to the standards now set even for reconnaissance mapping (fig. 2). Some of the mapping now being done is in areas of special economic interest on scales of 1:63,360 or larger, but most of the mapping in progress elsewhere is being done on a scale of 1:250,000, in order to cover the region as quickly as possible. Apart from studies related to mineral and engineering problems (see pages A4–A14 and pages A19–A22, respectively), the principal areas of geologic field work during the past year were in the Brooks Range, the Koyukuk Cretaceous basin, the Tofty-Eureka district, the Matanuska Valley, the Copper River basin, the eastern Chugach Range, and southeastern Alaska.

Geology of the southern part of the Brooks Range

As a part of reconnaissance mapping of the south half of the Brooks Range, Brosgé and Reiser completed a geologic map of the Wiseman quadrangle and mapped much of the Chandalar quadrangle. The rocks in this area consist largely of metamorphosed Paleozoic sedimentary rocks intruded by granite and basic rocks. Metal prospects occur near granite masses and on strike with them, and copper is associated with a few of the basic intrusives (Art. 161).

Cretaceous rocks of the Koyukuk basin

Reconnaissance mapping and stratigraphic studies by W. W. Patton in the Koyukuk Cretaceous basin of western Alaska, which may contain much petroleum (Miller and others, 1959), shows that late Early Cretaceous rocks in the Kateel River quadrangle are bounded on the north by the folded Early Cretaceous and older volcanic rocks of the Hogatza Arch. Both the volcanics and sediments are capped by Quaternary flows as much as 700 feet thick, but the northern and eastern limits of the Cretaceous sediments beneath these flows and the alluvium are clearly shown by several aeromagnetic profiles that cross the basin (Zietz and others, 1959).

Geology of the Tofty-Eureka district

In the Tofty-Eureka district in central Alaska, D. M. Hopkins and Bond Taber found that the northern limit of outcrop of a sequence of rocks many thousands of feet thick, consisting of basal orthoquartzite that grades upward to graywacke, coincides approximately with the northern limit of the Early Cretaceous geosyncline in which the sequence was deposited. They distinguished intrusive rocks of two ages, one probably of Early Cretaceous and the other of Late Cretaceous age, and found that tin is associated with the earlier intrusives and gold with the later. They also found that the gentle valley slopes underlying the placers in the area, at first thought to be pediments carved by minor tributaries, were formed instead by trunk streams flowing east or west, which during most of Pleistocene time were cutting into their south banks and simultaneously deepening their valleys.

Stratigraphy of the Matanuska formation

The rocks that make up the Matanuska formation in the Matanuska Valley, Nelchina area, and Copper River lowlands were found by Grantz and Jones (Art. 159) to range in age from Albian to Late Maestrichtian and to be separated at three stratigraphic levels by unconformities. Although the gross stratigraphic succession is similar in all these areas, the details of the succession change significantly between the Nelchina area and the Matanuska Valley. The formation is more highly deformed in the Matanuska Valley than in the other areas.

Geology of the eastern part of the Chugach Mountains

The lithologic character and general structural pattern of complexly folded sedimentary, volcanic, and metamorphic rocks have been determined by Earl Brabb and D. J. Miller in a strip crossing the previously unknown eastern part of the Chugach Mountains. They discovered that the argillite-graywacke sequence exposed on Barkley Ridge in the southern part of the

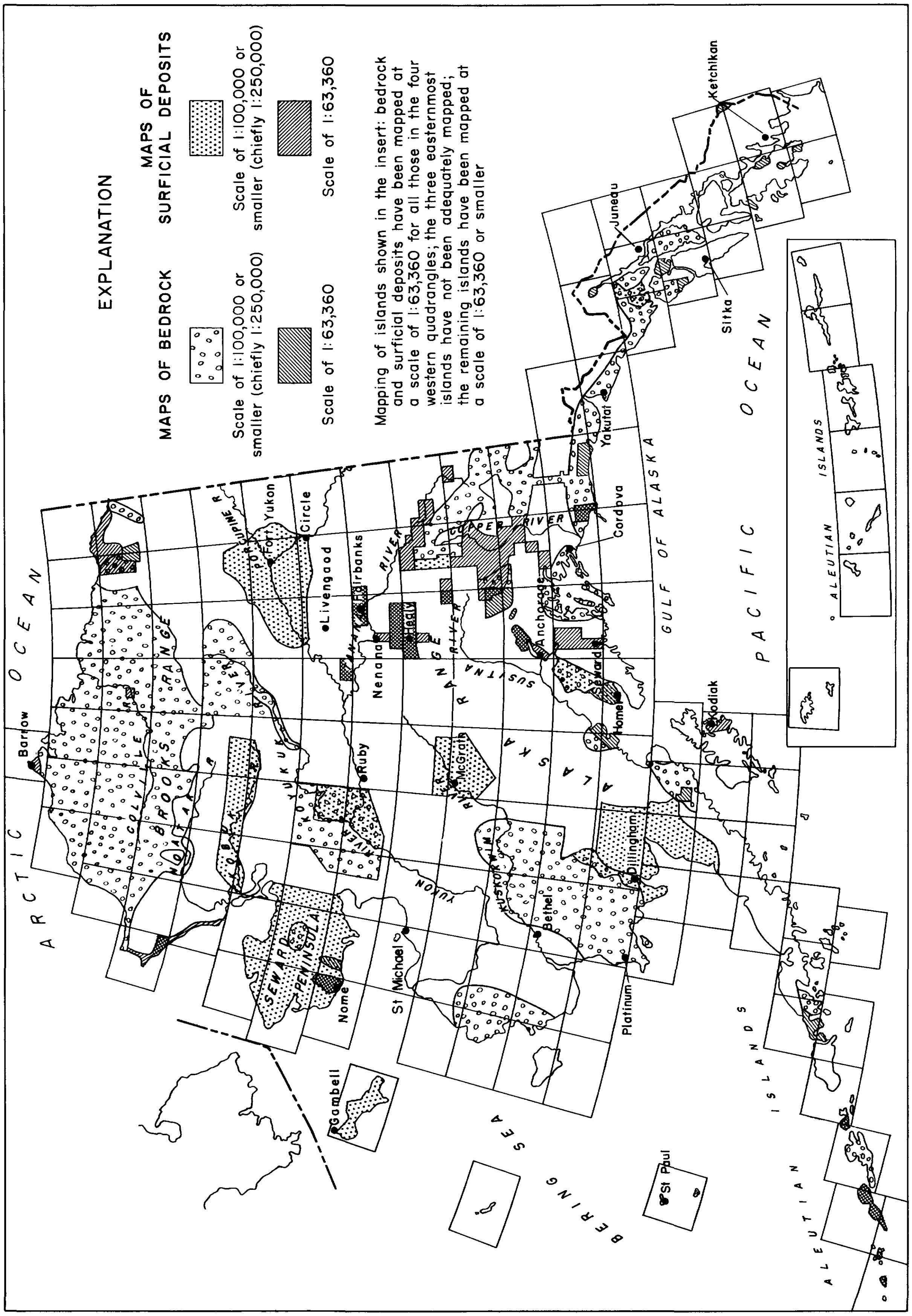

FIGURE 2.—Map of Alaska showing the location of areas where available geologic maps meet reconnaissance standards.

area is of Late Cretaceous or Paleocene age. Some copper and gold mineralization is associated with dioritic intrusives. They found evidence of two major glaciations, both presumably Wisconsin in age, and they also found evidence of late Wisconsin and Recent uplift.

Geology of Admiralty Island

The work of E. H. Lathram and others has shown that the metamorphic rocks forming the backbone and western side of Admiralty Island (including the Retreat group, previously thought to be of Triassic to Cretaceous age) are Silurian and Devonian. There is evidence for three periods of folding, all of which may be later than Early Cretaceous. Most of the folds are overturned to the southwest, but a few are overturned to the northeast. The rocks are intruded by many small stocks and by a batholith having an area of at least 150 square miles. Migmatites related to two of the stocks show signs of mineralization (Berg, Art. 19).

Reconnaissance aeromagnetic surveys of sedimentary basins

Analysis of aeromagnetic profiles across the Yukon Flats indicates that magnetic "basement" underlies most of the area at no great depth (Zietz and others, Art. 36). Only in relatively small parts of the area have low magnetic gradients been found that might indicate possible thick sequences of sedimentary rock. Aeromagnetic traverses across the Bethel lowland show that it is not a simple structural basin but is underlain by four northeast-trending belts, two where magnetic rocks are relatively near the surface, and two where magnetic rocks lie at considerable depth. East-west aeromagnetic lines flown across the Cook Inlet-Susitna lowland between Chelatna Lake and Seldovia, show a line of abrupt change in magnetic pattern that crosses the Susitna and Beluga lowlands and coincides in part with the Castle Mountain fault (Grantz and others, unpublished data). Great thicknesses of sedimentary rocks probably do not occur north or northwest of this line. South of this line, however, thick sections may underlie part of the Beluga lowlands and are known to be present southeast of the line in the Cook Inlet area. A total intensity aeromagnetic contour map and a gravity survey indicate that in places within the southern half of the Copper River basin sedimentary rocks are thick enough to have oil possibilities (Andreasen and others, unpublished data).

Tectonic provinces of Alaska

A tectonic map on a scale of 1:2,500,000, compiled by George Gryc and others, shows that Alaska is made up of a series of arcuate geosynclinal and geanticlinal belts that, except for the Brooks Range geanticline, are approximately parallel to the coast of the southern part of Alaska. These major tectonic belts are similar to those known further south on the North American continent. The Arctic Coastal Plain and the floor of the Arctic Ocean off Alaska, like the central interior of the United States and Canada, was probably a platform or shield until the beginning of Cretaceous time. The Brooks Range compares tectonically to the Rocky Mountains, the Central Plateau region of interior Alaska to the Basin and Range province, the Alaska Range and associated Talkeetna Mountains to the Sierra-Cascade province, the Cook Inlet–Matanuska Valley lowland to the Great Valley of California, and the Chugach and St. Elias Ranges and the Kenai Mountains to the California and Oregon Coast Ranges.

Glacial history and distribution of surficial deposits in Alaska

Coulter, Hopkins, Karlstrom, Péwé, Wahrhaftig, and Williams have compiled a map on a scale of 1:2,500,000, which shows the limits of past ice advances of post-Altithermal or Recent, post-Illinoian, pre-Altithermal, Illinoian, and pre-Illinoian ages throughout Alaska. One of the interesting things brought out by this compilation is that during each advance glaciers have been most extensive on the south side of mountain ranges and most restricted on the north sides—a rain shadow effect demonstrating that precipitation sources lay to the south and southwest in the Pacific Ocean and perhaps the Bering Sea during at least the last half of Pleistocene time. Another map of Alaska on a scale of 1:1,584,000 compiled by Karlstrom and others (Art. 154) shows the distribution of surficial deposits (including glacial deposits, loess, alluvium, coastal sediments, and volcanic deposits) and also the location of ice fields and glaciers, and major faults that have displaced surficial deposits. It should be of considerable use in state-wide planning of engineering projects.

In the Johnson River area on the northeast side of the Alaska Range, G. W. Holmes (1959d) has recognized three major glacial advances in his summary of the Quaternary history of the area. In the Cook Inlet area Karlstrom (1959 and Art. 153) has established a Quaternary chronology of 5 major glaciations and has correlated this glacial sequence with that of the mid-continent area of the United States. In the upper Kuskokwim region, Fernald (1959) has differentiated and mapped the extent of two ice advances. Other recent observations on the extent, age, and origin of surficial deposits are reported in papers by Coulter (Art. 160), Lewis (1959a,b), Nichols (Art. 162), Williams (1959 and Art. 152), and Williams, Péwé, and Paige (1959).

HAWAII

The Geologic Division's current work in Hawaii is mainly concerned with investigations of alumina-rich soils, and with observations on the Hawaiian volcanoes.

Alumina-rich soil and clay

Alumina-rich soils developed on basaltic rocks in the Hawaiian Islands are being investigated by S. H. Patterson to determine both their economic significance and the geologic factors influencing their distributions. This work, which is being done mainly in Kauai, is an extension of earlier reconnaissance investigations by J. B. Cathcart of the Geological Survey and Professors G. D. Sherman and A. T. Abbott of the University of Hawaii. Kauai, as one of the geologically older island volcanos of the Hawaiian group, is more deeply weathered than the younger islands. Work to date by Patterson indicates the Kauai deposits are submarginal as bauxite ore.

On the island of Hawaii G. D. Fraser (Art. 163) has mapped an extensive and deeply weathered pyroclastic deposit known as the Pahala ash. This bed, locally several feet thick, is now known to be a unique horizon marker in the Mauna Loa-Kilauea lava sequence and is believed by Fraser to have emanated from Kilauea as phreatomagmatic explosions. Composed largely of pumiceous material, its weathering to high-alumina clay has proceeded more rapidly, geologically, than weathering of basalt.

Ultramafic differentiates in the Kaupulehu flow

A remarkable "boulder bed" composed essentially of ultramafic inclusions has been exposed by a new road cut in the 1801 Kaupulehu flow on Hualalai Volcano. Locally this "conglomerate" contains less than one percent lava matrix and is up to 9 feet thick. The mineral and chemical composition of the olivine-rich and pyroxene-rich nodules are being studied in great detail by D. H. Richter and K. J. Murata for their significance in magmatic differentiation of primary basaltic magma.

Recent volcanic activity at Kilauea-Iki and Kapoho

Recent volcanic activity on the island of Hawaii, beginning with a summit eruption at Kilauea-Iki in November 1959 and ending with a flank eruption at Kapoho in February 1960, was observed and analyzed by geologists D. H. Richter and C. K. Wentworth, geochemists K. J. Murata and W. U. Ault, and geophysicists J. P. Eaton and H. L. Krivoy of the Geological Survey's Hawaiian Volcano Observatory.

The recent series of eruptions at Kilauea were presaged by a swelling of the volcano from October 1958 to February 1959, measured by the Survey's newly developed portable tiltmeter. The swelling subsided until August when, accompanied by a series of earthquakes, it commenced again. During the next few months the rate of swelling increased and the series of earthquakes, originally centered 35 miles below the surface, became shallower and more numerous. A great flurry of tiny, near-surface earthquakes centered on the edge of the crater heralded the violent summit eruptions at Kilauea-Iki from November 14 to December 20, 1959. Although the swelling subsided slightly during the eruptions, it continued at an increasing rate until January 13, 1960 when an eruption occurred on the flank of the volcano at Kapoho 24 miles away, an event also foreshadowed by a flurry of local earthquakes. The volcano then settled dramatically as the magma reservoir was drained, and activity culminated in a series of small collapses of the crater floor.

Sixteen phases of the eruption in the summit crater were recorded in the period November 14 to December 18, 1959, each manifested by geyser-like action with fountains up to 1,900 feet high. The lava temperature reached a maximum of 1190° C. The depth of the lava lake exceeded 400 feet and the thickness of the ash fall at the crater rim exceeded 100 feet. The crust on the lava lake has been penetrated by drilling, and devices installed in the hole for geothermal studies have recorded a thermal gradient of 100° C per foot in 7 feet of crust. The lava from the summit eruption contains 46.3 to 49.5 percent SiO_2.

Among the gases identified in the eruption, SO_2 reached concentrations of one percent within the high-temperature interior of the newly-formed pumice cone, and in Hilo, 22 miles distant, the SO_2 content of the air reached 2 ppm. The ratio of CO_2/SO_2 ranged from 0.6 to 2,000 at different gas-venting localities. $CuCl_2$ emission was detected in volcano flames during eruption.

The flank eruption at Kapoho was predicted by seismic station monitoring, and public warnings were issued after the Kapoho graben sank three feet. Eruption began on January 13, 1960 and ingress of ground water caused violent steam emission coincident with lava eruption. Flows rapidly changed from pahoehoe to aa. The lava that issued from Kapoho was more viscous, reached a lower maximum temperature, and contained more silica (50.2 percent SiO_2), plagioclase, and pyroxene and less olivine than the lava that came from the summit eruption. The Kapoho eruption is interpreted as a more advanced differentiate of the Hawaiian primary magma.

PUERTO RICO AND THE CANAL ZONE

The U.S. Geological Survey has been studying the geology of Puerto Rico in cooperation with the Economic Development Administration of the Commonwealth of Puerto Rico. The project was started in 1952, and its purpose then was only to investigate the mineral resources, but in 1955 its aims were enlarged to include mapping the entire island on a scale of 1:20,000.

The mountainous central part of the island is made up of rocks of Late Cretaceous and early Tertiary age in a complexly faulted northwest-trending anticlinorium. Most of the stratigraphic units are lenticular and consist of volcanic rocks or of sedimentary rocks containing volcanic fragments (Berryhill, Briggs, and Glover, 1960). These units are cut by several large bodies of intrusive rock. The coastal border of the island is underlain by gently dipping younger rocks of Tertiary age.

In the east-central part of the central mountainous area, graben and horst structures occur in a zone of complex faults (Briggs and Pease, Art. 167), and in south-central Puerto Rico small thrust faults have been recognized by Glover and Mattson (Art. 166). In the north half of the mountainous area hydrothermally altered rocks containing quartz, pyrophyllite, alunite, and kaolin group clays occur at several places along a northwest trending belt (Hildebrand, 1959; Pease, Art. 165).

In the Canal Zone and adjacent parts of Panama, geologic studies have been carried on intermittently by W. P. Woodring since 1947. The principal objectives have been to determine the geologic history of the land bridge, but geologic mapping by the Geological Section of the Special Engineering Division of the Canal Zone has been compiled and is included in Chapter A of Professional Paper 306 on the geology and Tertiary molluks, published in 1957. The description of the Tertiary mollusks is continued in Chapter B (Woodring, 1959a).

WESTERN PACIFIC ISLANDS

The scattered islands and the island groups of the Western Pacific (fig. 3) represent the exposed regional geology of an area greater than that of the continental United States. Up to 1946, little detailed geologic information about this area was available; today, as the result of geologic studies supported or done in cooperation with several agencies of the Department of Defense, with the U.S. Atomic Commission, and with the National Research Council, it is abundant. Some of the islands, indeed, are among the most intensely studied places on earth.

Geologic contrasts between the island arcs and islands of the western Pacific basin

The contrasting geologic nature of islands situated on the two major island arc systems bounding the western side of the northern Pacific Basin are illustrated by differences in the stratigraphic successions of the rocks of Okinawa and Ishigaki in the Ryukyu Islands and of Guam in the southern Mariana Islands and Yap in the western Caroline Islands. On Okinawa, an island of the western arc, raised late Tertiary and Quaternary reef limestones and associated sediments overlie a thick sequence of tilted Miocene marls and complexly folded and faulted low-grade metamorphic geosynclinal deposits mostly of late Paleozoic age (Flint, Saplis, and Corwin, 1959); those of Ishigaki rest on faulted Eocene limestones, conglomerates and volcanic rocks, and on probable late Paleozoic intermediate-grade metamorphic geosynclinal sediments that have been intruded by granites of late Mesozoic or early Tertiary age (Foster, Art. 170).

On Guam, an island of the eastern arc, uplifted reef limestones and argillaceous equivalents overlie a thick sequence of Eocene and Miocene volcanic rocks and associated sediments, most of which were deposted at or below sea level but are now raised to elevations of as much as 1,300 feet and more above sea level (Tracey and others, 1959). At Yap, late Tertiary and Pleistocene reef limestones are lacking; the basement rocks include Miocene volcanic rocks, a breccia of undetermined Miocene or Oligocene age, and older undated metavolcanic deposits that have been intruded by ultramatic rocks (Cole, Todd, and Johnson, 1960).

Whereas basement rocks in both arcs are now exposed above sea level, basement rocks in the Northern Marshall Islands, a group in the western Pacific basin east of the arcs, now lie at appreciable depths below sea level. At Eniwetok, Quaternary reef limestones rest on thick Miocene and Eocene reef limestones that in turn overlie a flow of olivine alkali basalt at depths of more than 4,000 feet below sea level (S. O. Schlanger and G. A. MacDonald, unpublished data).

Regional stratigraphic and paleontologic studies

Large paleontologic collections, especially of microfossils and Mollusca, have made it possible to correlate the Tertiary limestones throughout the Western Pacific. W. Storrs Cole reports a comparable sequence of larger Formaminifera, ranging in age from Eocene to Recent, at widely separated localities in the Fiji Islands, the deep drill holes at Bikini and Eniwetok, and the raised limestones of Saipan, Guam, and the Palau Islands. The sequence can also be correlated

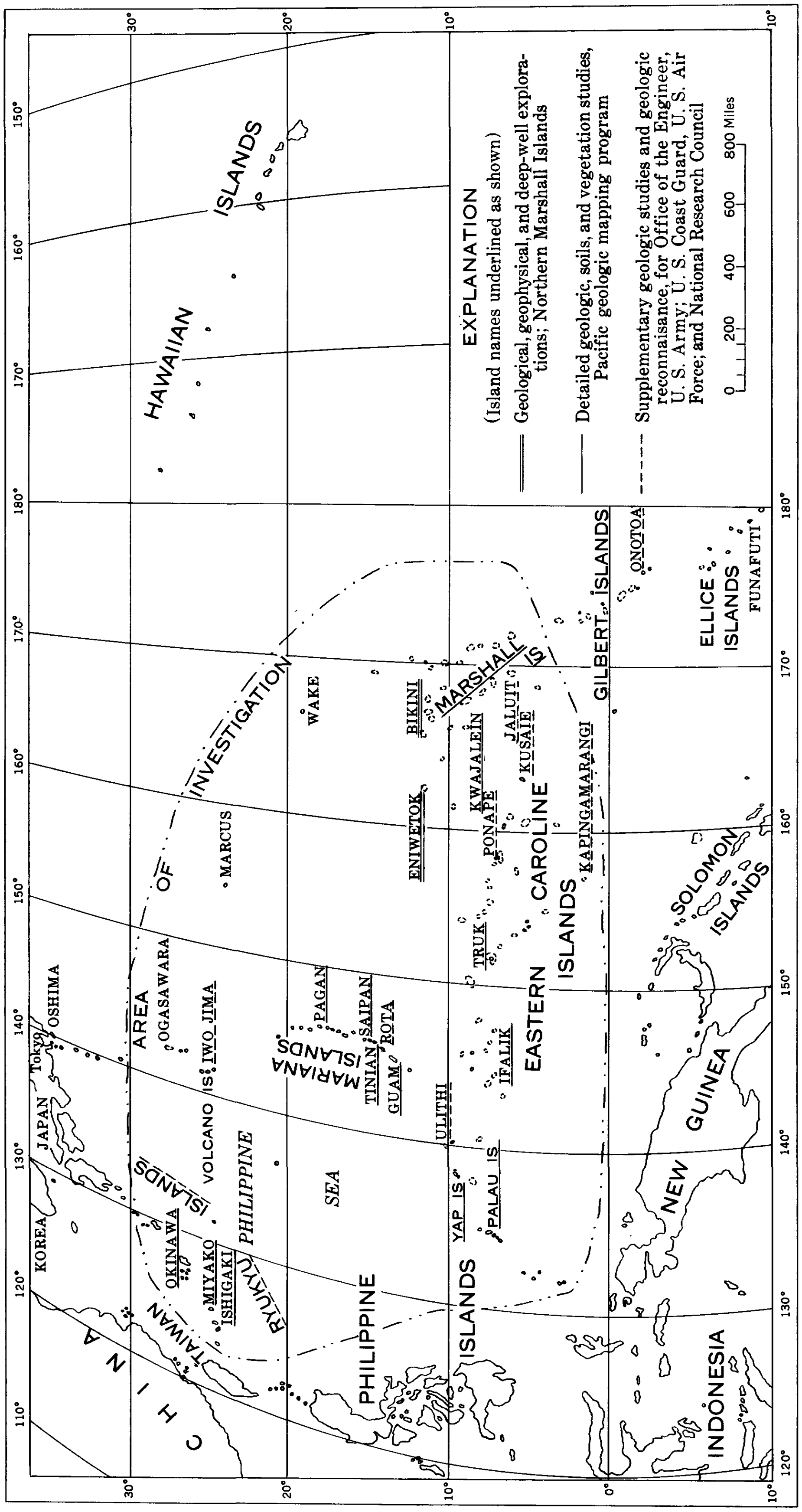

FIGURE 3.—Index map of Western Pacific Islands showing areas investigated by the Geological Survey.

with the one previously well-established in Indonesia. Studies of smaller Foraminifera by Ruth Todd, of Mollusca by H. S. Ladd and F. S. MacNeil, of corals by J. W. Wells, of discoasters by M. J. Bramlette, of fossil algae by J. H. Johnson, of fossil Mammalia by F. C. Whitmore, and of fossil pollen and spores by E. S. Leopold, indicate that similar successions and correlations over large areas of the Pacific may be possible for other fossil groups.

F. S. MacNeil has found that the fossil gastropods of Okinawa correlate with other described faunas of the Far East of late Oligocene to Pleistocene age. The faunal succession indicates cooling of marine waters in that area from late Miocene to early or middle Pliocene, followed by warming in late Pliocene. The Pleistocene deposits in Okinawa consist of reef limestones, presumably deposited during warm-water interglacial stages when sea level was high; unconformities in these deposits presumably represent glacial intervals during which the water was cool and sea level was low.

Fossils of the extinct deer *Metacervulus astylodon* (Matsumoto) have been identified by F. C. Whitmore (Art. 171) in collections from Ishigaki-Shima, Ryukyu Islands, in rocks of Pleistocene or late Pliocene age; these and other data suggest that mammals migrated from South China, via Taiwan, during a period of emergence in late Pliocene or Pleistocene time. Younger bones of a pig, probably *Sus leucomystax riukiuanus* Kuroda, have been dated by C_{14} methods to be at least 8,500 ±500 years old.

Origin of tropical soils and bauxite on the higher islands

The tropical and subtropical islands, as they are now and were during their recent geologic history, present a wide range of conditions for the development of tropical soils and bauxites and for the dispersal of vegetation. S. S. Goldich, who investigated bauxite deposits of the Palau Islands, and C. H. Stensland, who has studied and mapped soils on many of the islands, have independently arrived at the conclusion that surficial deposits of the higher, larger islands are principally the products of weathering during late Tertiary and possibly early Pleistocene time, and that they reflect a complex geologic history.

Migrations of land and marine faunas and floras, and of man, between islands of the Western Pacific have long been subjects of study and controversy. H. S. Ladd (1960 and Art. 172) has concluded, on the basis of fossil Mollusca from the islands and in the light of recent discoveries from drilling, dredging, and submarine mapping, that many islands and reefs existed within the Central and Western Pacific throughout the Tertiary and that the island areas may have been centers of dispersal for many elements of the Indo-Pacific fauna.

ANTARCTICA

The Geological Survey has participated in scientific work undertaken by the United States in Antarctica during most austral summers since 1954–55, and presently is working there with support from the National Science Foundation. Even though the work undertaken thus far has not been extensive, it has helped to indicate the geologic character of this little known continent.

Geologic mapping by Hamilton and Hayes (1959a) in Taylor Valley, South Victoria Land (fig. 4) has outlined a composite batholith, consisting of various kinds of granitic rock, intruded into the western side of a belt of metasedimentary rocks, 15-miles wide, roughly parallel to the coast. Unconformably overlying the crystalline rocks is the nearly flat-lying Beacon sandstone, within which are sills of differentiated diabase up to 1,300 feet in thickness. These sills and the Beacon sandstone are displaced by several large normal faults (Hamilton and Hayes, Art. 173).

Structurally, the mountain belt that borders the Ross Sea and Ross Ice Shelf, and includes the Horlick Mountains (fig. 4) has been regarded hitherto as a part of the "Great Antarctic Horst," which is marked by a nearly continuous mountain chain that crosses Antarctica near the South Pole. Doubt has been cast on this view, however, by Hamilton's reinterpretation of rocks and structures, and by the fossils and radiometric age determinations that are now available. These support the hypothesis that the mountain chain is a belt of rocks that was metamorphosed and intruded by batholiths in Cambrian time (Hamilton, Art. 174).

Samples of coal and fossil plant materials from the Beacon sandstone in a portion of the Central Range, Horlick Mountains (fig. 4) have been studied by James M. Schopf. He finds that some of the coal is semianthracite, and that it contains both megafossils and microfossils characteristic of the Gondwana coal measures.

A geologic reconnaissance of the western and central parts of the Thurston "Peninsula" was made by Harold A. Hubbard while working with the scientific group of the 1960 Amundsen-Bellinghausen Seas Expedition. Bedrock samples were taken at four localities; the rock at all of them is a fine- to medium-grained hornblende-diorite.

In Marie Byrd Land, Eugene L. Boudette completed a geologic reconnaissance along the route of the austral

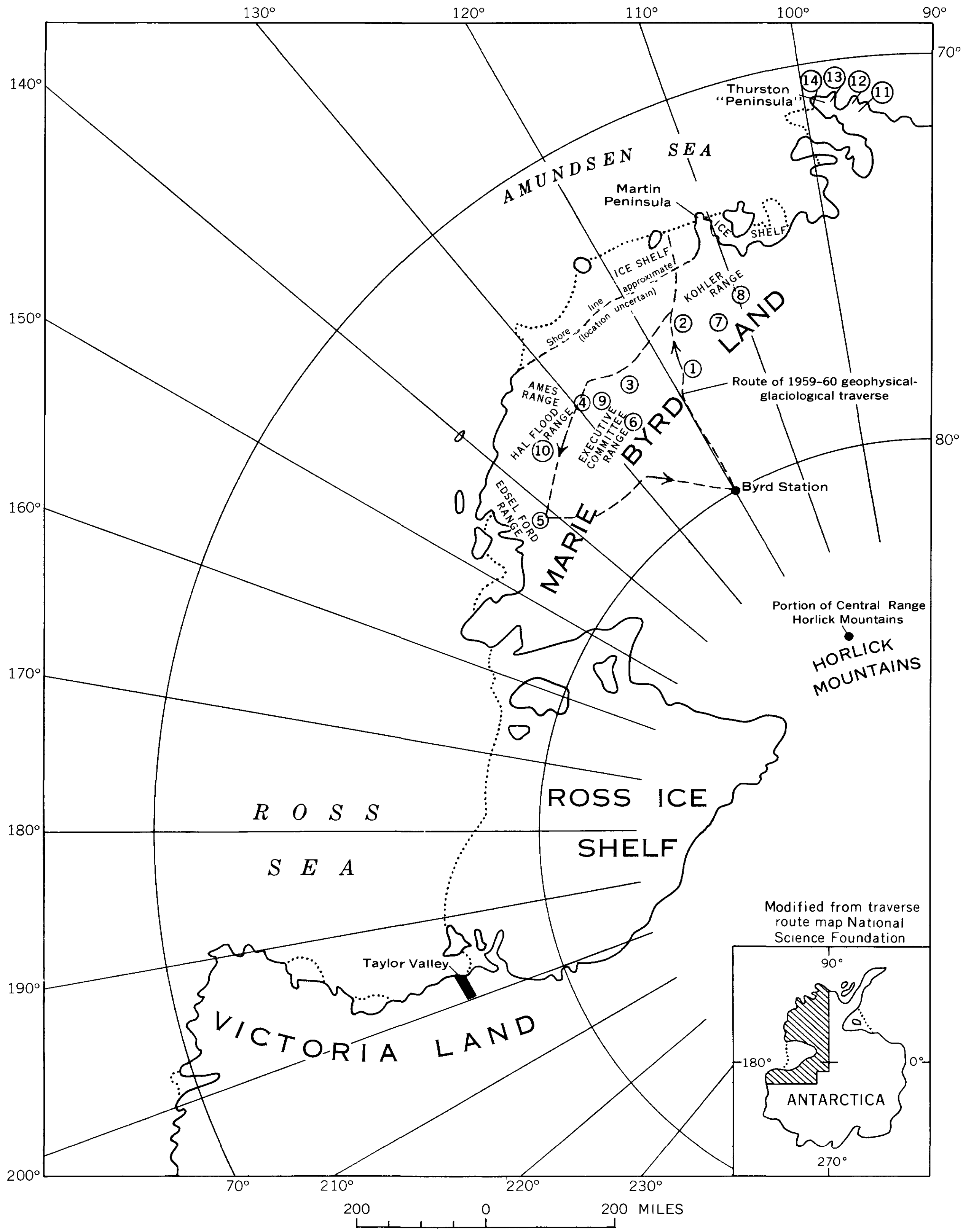

FIGURE 4.—Index map of part of Antarctica showing areas of geologic reconnaissance and geologic mapping by the Geological Survey in 1958, 1959, and 1960. Locations are indicated for bedrock stations in Marie Byrd Land (circles 1 through 5), mountain groups observed at variable distances along the route of the 1959–1960 Byrdland Traverse (circles 6 through 10), and bedrock stations on the Thurston "Peninsula" (circles 11 through 14).

summer 1959–60 geophysical-glaciological traverse (fig. 4). Preliminary results from his investigation show that two mountain groups, provisionally called the "Crary" and "Toney" Mountains, are composed of basalts and related rocks, and that they contain stratiform volcanic cones rising 5,000–7,000 feet above the ice-plateau surface that show little erosional destruction. The south end of the Ames Range and a range previously surveyed in 1959 contain felsic to intermediate volcanics. In the Edsel Ford Ranges granite intrudes metagraywacke. Mountains in the Executive Committee Range, the Ames Range, Mount Petras, Mount Berlin in the Hal Flood Range, and a mountain group provisionally named "Mount Takahe" were observed from a distance to be of similar physiographic form. The Kohler Range and "Mount X-Ray" (also provisionally named) do not have diagnostic physiographic forms and they may consist of non-volcanic rocks. From Boudette's interpretation of bedrock exposures and from seismic profiles made by F. K. Chang (traverse seismologist), it seems likely that much of Marie Byrd Land is a volcanic archipelago.

EXTRATERRESTRIAL STUDIES

A terrain study of the moon has been made by stereoscopic methods by R. J. Hackman (see Art. 62) and A. C. Mason, under the auspices of the Office of the Chief of Engineers, U.S. Army. Among the features mapped are mountains, maria, craters, rays, and rills. Pre-maria craters are distinguished from post-maria craters, and flat-bottomed craters are distinguished from those having simple or compound central cones. The data are presented on a photomosaic monotone, but will later be plotted on a map at a scale of 1:5,000,000 now being prepared by Army Map Service. A bibliography of about 1,000 references concerning the surface of the moon has also been completed.

E. M. Shoemaker has made a detailed study of Copernicus, and compared this and other lunar craters with comparable earth features. Shoemaker interprets the rays that extend as much as 400 miles from the crater Copernicus as splashes of crushed rock derived from the impact of large fragments ejected when Copernicus was formed; many of the rays start from visible impact gouges as much as 5 miles long.

As the result of the work of R. E. Dietz, of the Naval Electronics Laboratory, and others, shatter cones are now recognized as a criterion of terrestrial impact structures, the study of which aids in the interpretation of similar features on the moon. The discovery of coesite, a high-pressure form of silica, at Meteor Crater, Ariz., has furnished another criterion for the recognition of terrestrial impact structures (see p. A58).

Tektites (small pieces of glass found in widely separated localities and thought by some to be of extra-terrestrial and possibly lunar origin) have been found by Frank Senftle to have little or no magnetic susceptibility. This indicates that the iron in them must be in solution, and hence that they must have been heated well above 1400° C., which in itself implies an extra-terrestrial origin.

R. E. Wallace (1959) has described a simple and rapid graphical method, using a stereographic net, of solving certain problems related to the orbits of artificial satellites.

GEOLOGIC INVESTIGATIONS IN FOREIGN NATIONS

Under the auspices of the International Cooperation Administration, the Geological Survey cooperates with a number of foreign governments in activities broadly designed to aid the growth of their economies through development of their mineral resources. These activities are of several kinds: (a) geologic training of foreign nationals, accomplished by assigning them to Survey field parties and laboratories, or by lending experienced Survey geologists to foreign universities or geological surveys; (b) advisory service; and (c) geologic mapping, geophysical surveys, and similar studies of areas favorable for the occurrence of mineral resources. Although the training and advisory activities are perhaps of the most far reaching significance, they do not yield new geologic information directly and are not described further here (see p. A93, however, for a list of the activities involved). Some of the new information from the field studies is summarized briefly in the following paragraphs, with emphasis on that which is of broad scientific or economic interest.

Chromite deposits in the Philippines

An investigation of the chromite deposits of the Philippines, in cooperation with the Philippine Bureau of Mines, was begun in 1955 and is continuing under the direction of D. L. Rossman. Four 15-minute quadrangles in Tambales province have been mapped, three others have been partly mapped, and several chromite bodies have been mapped in detail. These field investigations have shown that the Tambales complex is a layered intrusion at least 100 miles long and 30 miles wide, with a stratigraphic thickness of at least 10,000 feet. The lower part of the complex consists of a peridotite zone at least 5,000 feet thick, a central transition zone about 500 feet thick, and an upper gabbro zone about 5,000 feet thick. The small-scale layering within the major units crosses lithologic boundaries, unlike similar structures in the Bushveld and Stillwater complexes, and cannot, therefore, be used as a guide to predict structure or location of chromite ore bodies. Mapping, however, has shown that all of the chromite ore bodies occur either in the transition zone or in the peridotite within a few hundred feet of the transition zone. Furthermore, it has been found that metallurgical-grade and refractory-grade chromite deposits are enclosed by different rocks. Drilling based on these observations has thus far proven the existence of about 500,000 tons of high-grade chromite ore.

Coal in Pakistan

Although the Geological Survey's program in Pakistan consists mainly of advisory assistance and training, it also includes demonstration projects conducted by the Survey staff, involving mapping and appraisal of selected economically-important resources such as coal, iron, and chromite. As Pakistan currently imports about 20 million dollars worth of coal each year, three of the Geological Survey demonstration projects in West Pakistan have been established in coal-bearing areas to aid the expansion of coal mining and help reduce coal import expenditures.

Pakistan coals are in outer mountain belts in the Himalayan Mountains system. They are of Eocene age and many of them are of good quality, subbituminous rank. The reserves in the areas studied are tentatively estimated to be more than 200 million tons. Studies of chemical constituents, physical properties, and lateral changes in thickness have made it possible for the first time in Pakistan to classify reserves by quality, rank, and utilization possibilities, and also to compare the coal-forming environments in Pakistan with those in other countries having similar coals.

Iron deposits in Brazil

Among the several field activities of the Geological Survey in Brazil, the investigation of iron and manganese in the Quadrilátero Ferrífero of central Minas Gerais, done in cooperation with the Departamento Nacional da Producão Mineral, has been the most extensive. In progress since 1950, the work has involved geologic mapping, at a scale of 1:25,000, of thirty-five 7½-minute quadrangles. These maps are now largely completed, and a map, on a scale of 1:200,000, of the entire Quadrilatero Ferrifero has been recently compiled by the Departamento Nacional de Producão Mineral and U.S. Geological Survey (1959).

The hematite in the Quadrilátero Ferrífero is in banded iron formation associated with metasedimentary rocks, intruded by granitic rocks. The ore deposits have been found to be localized in the troughs of synclines, and less frequently on the crests of anticlines; a few, however, show no apparent structural control. The area contains several billion tons of high-grade (<65 percent Fe) hematite ore and many billion tons of intermediate grade (35 to 40 percent Fe) itabirite, much of which can be concentrated by simple gravity methods.

Mineral and fossil fuel potential of Southern Peru

During 1958 and 1959 the Survey cooperated with the Peruvian Instituto Nacional de Investigaciones y Fomento Mineras in a project to evaluate the mineral potential of seven departments in southern Peru. The reports by Kiilsgard and Olive have been published in Spanish (Plan Regional Para el Desarrollo del Sur del Peru, 1959) and include a geologic map, on a scale of 1:1,000,000, of southern Peru, a map on the same scale showing the location of all known mineral deposits, and geologic descriptions of more than 100 individual deposits or districts.

One of the principal conclusions of this study is that southern Peru has large, undeveloped mineral resources, particularly porphyry copper deposits, but that it will be expensive to bring these deposits into production. To stimulate exploitation of these resources, the report recommends the Peruvian Government make detailed geologic studies of the following favorable areas: (a) porphyry-copper belt extending along the western front of the Cordillera Occidental, from Arequipa to the Chilean border; (b) a belt of contact metasomatic-copper deposits extending northwest across the Andean Altiplano, in the departments of Cuzco and Apurimac; (c) ore-bearing volcanic rocks in the Cordillera Occidental; and (d) the extensive but heretofore inaccessible gold-bearing area along the eastern flank of the Cordillera Oriental.

Metalliferous deposits in Chile

The U.S. Geological Survey continued to work in cooperation with the Instituto de Investigaciones Geologicas of Chile during 1958 and 1959. Reconnaissance field investigations in the Province of Tarajaca, made for the purpose of organizing a long-range project of detailed mineral investigations, resulted in the discovery of several large alteration zones that show many of the characteristics of porphyry copper deposits. Two of these zones are currently being mapped in detail.

Metalliferous deposits in Chile tend to be restricted to well defined metallogenic provinces, each characterized by a dominant mineral or mineral assemblage or by particular geological features. The most important ore deposits are those of copper, iron, silver, gold, and manganese. The primary minerals represented are few in number and most are simple sulfides and oxides; more complex sulfo-salts are scarce. Secondary minerals in great variety are important constituents of the ores. Many of the ore deposits are situated along well defined structural lines, several hundred kilometers long, that parallel the structural grain of the Andes.

The deposits, with few exceptions, are found in sedimentary or volcanic rocks that range in age from Jurassic to Late Cretaceous or in intrusive rocks of Late Jurassic or Late Cretaceous age. Most deposits are genetically related to intrusive bodies which have an average composition within the range of diorite-granodiorite.

The metalliferous deposits can be classed as hydrothermal, sedimentary, and contact-metamorphic. Copper deposits are typically hydrothermal. Some of the manganese deposits are sedimentary. And most of the iron ore deposits are contact-metamorphic. The hydrothermal deposits, the most abundant and most important economically, were formed at moderate to low temperature and pressure.

INVESTIGATIONS OF GEOLOGIC PROCESSES AND PRINCIPLES

Although the investigations described in the preceding sections of this report are dominantly research activities, they are either stimulated by economic objectives or by the need to learn more about the geology of specific areas. A third general type of research, classed here as topical, is undertaken because of the need to know about geologic processes or principles. Although these investigations do not necessarily focus on immediate economic or areal geologic problems, they do provide the stimulation and basis for advances in all phases of geology.

The research currently in progress on geologic processes and principles is grouped in the main categories of paleontology; geomorphology and plant ecology; geophysics; mineralogy, geochemistry, and petrology; and isotope and nuclear studies.

PALEONTOLOGY

Paleontological studies that have to do mainly with stratigraphic correlation and other regional problems are described in the other sections of this report dealing with the geology of various areas. Findings that have to do with evolutionary development, ecology, and other subjects of general interest are reported here.

As a part of a study of the Late Cretaceous gastropods of Tennessee and Mississippi, N. F. Sohl has noted a large number of evolutionary trends or changes. For example, in the *Urceolabrum* lineage, the species increase in size (especially height), ornament complexity, and width of ornament spacing with time. In the bicostate group of *Turritella*, the lineage shows a decrease in the number of primary spiral cords with time.

From studies of *Baculites*, W. A. Cobban has stratigraphically zoned the Upper Cretaceous of the Western Interior, and correlated the zones with the European Cretaceous standards. His studies also reveal interesting changes in species with time—for example, *Sciponoceras gracile* migrated from the Gulf Coast region to Montana; during the course of its migration the adults became notably reduced in size, presumably because of cooler waters.

Fifteen floral zones are recognized in the upper Paleozoic systems in the United States by Read and Mamay (Art. 176). In order of decreasing age, the Mississippian zones are: *Adiantites*, *Triphyllopteris*, and *Cardiopteris*. The Pennsylvanian zones are: *Neuropteris pocahontas*, *Mariopteris pottsvillea*, *Mariopteris pygmaea*, *Megalopteris*, *Neuropteris tenuifolia*, *Neuropteris rarinervis*, *Neuropteris flexuosa*, *Lescuropteris*, and *Danaeites*. The Permian zones are *Callipteris;* the older *Gigantopteris*, *Glenopteris*, and *Supaia* floras; and the younger *Gigantopteris* flora.

A. R. Palmer (1960c), reports the preservation of copepods in rocks of Miocene age. This is the first description of fossils of this arthropod subclass. Despite their rare preservation, copepods have probably been in existence since early geologic times, but have evolved very slowly.

Preliminary studies by Henbest (Art. 177) of fossil spoor in the Morrow and Atoka series of Pennsylvanian age indicate that they are useful as indicators of environment and conditions of deposition, as well as in the local tracing of sedimentary facies. Henbest (Art. 178) has also developed petrologic criteria to distinguish agglutinated tubiform foraminifers from secreted forms where the shell material has been recrystallized.

Ecologic and morphologic analyses of 17 living species of the foraminiferan *Bolivina* off El Salvador by Patsy J. Smith indicate that some species show no variation in size or morphology throughout depth changes from 50 to 3,200 meters; others reveal great change. In species which change morphologically with depth, greatest abundance and largest size is reached at 800 to 900 meters, the depth zone of minimum oxygen and maximum nitrogen.

GEOMORPHOLOGY AND PLANT ECOLOGY

Many Survey projects are concerned with land forms and geomorphic processes, particularly if their emphasis is upon mapping surficial deposits, and many field geologists utilize and make observations on the distribution of natural vegetation in the course of their mapping. A few projects, however, are concerned with general principles in these fields and their results are summarized here.

Development of karst features

Two investigations have served to bring out some of the factors that control the development of karst phenomena. In Puerto Rico, Monroe (Art. 164) finds that karst type is a function of the homogeneity of the underlying limestone. Sinkholes occur where the terrane consists of alternating hard and soft beds of limestone, and tower-karst where the terrane is composed of homogeneous limestone. In the Shenandoah Valley of Virginia, Hack (Art. 179) has shown that solution cavities in carbonate rocks are more abundant in areas that receive waters of low pH draining clastic sediments than in areas where all the streams drain carbonate rocks.

Dynamic equilibrium in the development of landscape

In the Potomac River Basin, field studies, made by Hack and his associates, of soils, vegetation, and erosional features indicate that the "maturely dissected" landscape of this region was produced by the weathering and erosional processes that are going on at the present time, acting in dynamic equilibrium upon rocks of diverse character. Hack believes that this and other such landscapes may be end products of long-continued erosion under conditions similar to those of the present time, and that these processes can never lead to the formation of a peneplain. If this is true, the classical explanations of such landscapes in terms of landscape cycles should be discarded (Hack, 1960).

Formation of beaches and bars

McKee (1960b) and Sterrett have found from wave-tank experiments that the form and internal structure of beaches and bars are controlled by three factors: depth of water, intensity of wave action, and supply of sand. Offshore bars develop at the point of wave break. Where this occurs in very shallow water an emergent bar commonly forms; where it is in somewhat deeper water a submarine bar is built; where still deeper no bar develops. Increase in intensity of waves tends to build a bar toward and even onto the beach. Weaker waves build upward to form barriers with lagoons to shoreward. Abundant sand furnished on the seaward side of a developing bar, simulating conditions developed by some longshore currents, causes gently sloping, seaward-dipping beds to form. In contrast, shoreward-dipping strata of steeper angle are characteristic of bars developed where the sand supply is limited.

Plant ecology

A vegetation map of about 50 square miles of mountainous terrain in the Potomac River Basin, prepared by Hack in collaboration with John C. Goodlett of Harvard University, indicates that the distribution of tree species is closely related to topographic forms, soil, and geology as they exist today; they have concluded from this that the forest pattern is determined mainly by the water-in-soil requirements of individual trees rather than by the evolution of climax communities.

In Death Valley, Calif., Hunt (Art. 208) analyzed the geomorphic distribution of plants, and finds that xerophytes grow in the main and tributary washes of the grand fans, and phreatophytes grow at the foot of the fans where the ground water is shallow. Benchlands between the marshes commonly have an impermeable surface of desert pavement and are bare. The salt pan in the interior of the valley is devoid of flowering plants and ground around the foot of the fans that contains more than 5 percent of salts is also bare.

World vegetation classification

In the course of studies of vegetation patterns it became evident to Fosberg (1959b) that current vegetation classifications which involve the environment as well as the plants are not satisfactory for certain purposes. In attempting to ascertain which criteria pertaining to the plants themselves are suitable bases for a world-wide vegetation classification, he found that features of "structure" (the arrangement in space of the components of vegetation), and of "function" (features that suggest special adaptation to environmental situations, either present or past), provide a basis for classification that can be carried down to the level of formation and, if needed, subformation. Further subdivision, appropriate on a regional basis, may be made by taking into account floristic composition (i.e. the species present in the vegetation).

GEOPHYSICS

The physics of the earth is an extremely broad field which, logically defined, includes some branches of the geological sciences long known by other names—structural geology, for example. Defined in this way, many of the field investigations already described have to do with geophysics (and under even a narrow definition many of them are of interest to geophysicists). In this section, however, are described studies in more restricted fields, specifically: new measurements of the physical properties of rocks, work on permafrost, experiments and observations on rock deformation, and paleomagnetism. Work on the development of geophysical exploration methods is described on p. A16, geophysical work directly related to engineering problems on pages A19–A25, and results of aeromagnetic and gravity measurements in various areas are described on pages A29–A46.

PHYSICAL PROPERTIES OF ROCKS

The use of geophysical methods in exploration and mapping, and in the solution of many geologic and engineering problems depends on knowledge of the physical properties of rocks. Reported here are some of the new findings on the mechanical, electrical, magnetic, mass, optical, thermal, and thermodynamic properties of rocks.

Mechanical properties

In studying the change of strength of ice during the thaw period in Lake Peters, Brooks Range, Alaska, D. F. Barnes found that both strength and thickness decreased more rapidly in ice whose grains have predominantly horizontal crystallographic c-axes than in ice with vertical c-axes.

L. Peselnick has studied absorption of mechanical vibrations as a function of frequency in certain nearly isotropic rocks by determining (a) the pulse absorption at about 10^7 cycles per second, (b) the resonance decay at natural frequencies of about 10^4 cycles per second, and (c) the torsion pendulum absorption at about 10 cycles per second. Results of measurements on the Solenhofen limestone, a very fine grained, nearly isotropic rock, show that there is a slight but real change of absorption with frequency. (Peselnick and Outerbridge, Art. 182).

Using elasticity theory and underground measurements of the velocity of compressional and shear waves in a potash mine near Carlsbad, N. Mex., R. E. Warrick calculated the elastic moduli of the rocks in place; good values for Poisson's ratio are 0.28 for a salt pillar and 0.30 for a potash pillar.

Electrical properties

From a preliminary study of the effect of temperature on resistivity in rocks, G. V. Keller concludes that below about 400°C conduction in the mineral grains is controlled in good part by impurities but that between 400°C and 1,000°C it is ionic. It is difficult, however, to determine the mechanism of conduction in rocks because the rock samples undergo irreversible chemical and physical changes during the tests. Reductions in resistivity were accompanied in all cases by increases in the dielectric constant in the frequency range 300 cycles per second to 200 kilocycles per second. Unless the rock is heated above 150°C, its inherent resistivity is generally disguised by its water content.

Keller has also studied induced polarization in single crystals of some sulfide and oxide minerals by measuring over-voltage, surface impedance, and normal electrode potential (see also p. A17). Minerals with the highest surface impedance probably contribute the most to induced polarization. Measurements of the electrical transient voltage of various rocks gave the following results: disseminated sulfides have the greatest ability to polarize, followed in order by hematite iron ores, glacial till, fine-grained igneous rocks, sandstone and shale, felsic igneous rocks, limestone and dolomite, and ultramafic igneous rocks.

Magnetic properties

An absolute method of measuring magnetic susceptibility by means of a quartz helix balance has been developed by Thorpe and Senftle (1959); the sensitivity of the method for milligram samples is 10^{-10} cgs units. Measurements on natural brookite, anatase, and rutile, and on synthetic anatase and rutile over the temperature range of 4°K to 373°K show that the magnetic susceptibility is markedly affected by iron, magnesium, and other impurities (Senftle and Thorpe, 1959a, b).

J. R. Balsley and A. F. Buddington (1960) have found a distinct correlation of anisotropy of magnetic susceptibility with the fabric of granites and orthogneisses of the Adirondack Mountains. The direction of remanent magnetization is related to the mineralogical composition of the rocks.

Mass properties

Mean values of bulk density, porosity, permeability, thermal conductivity, and magnetic susceptibility have been determined by C. H. Roach, F. M. Byers, and G. A. Izett for granite, dolomite, and marble found on the Nevada Test Site. These rocks are all dense, as shown by their low permeabilities (less than 10^{-13} millidarcies). In the granite, they found a linear relation (with some scatter) between log magnetite in volume percent (M) and log susceptibility in cgs units (S). This may be expressed as $S = 4.3\ M^{1.4}$.

Phosphorescence and thermoluminescence

Preliminary results of an investigation by R. M. Moxham indicate that scheelite, kyanite, and fluorite have an infra-red phosphorescence that persists long enough to be observed on an oscilloscope, although total persistence is less than 10 milliseconds; the decay very nearly follows an exponential law. Investigations of the relation of thermoluminescence to wallrock alteration are discussed on p. A15.

Thermal properties

From measurements on duplicate samples of 93 specimens, representing 1,000 feet of limestone and 1,000 feet of dolomite from a deep well in West Virginia, Robertson (1959) found that the mean conductivity of the limestone is 6.77 x 10^{-3} cal per cm/deg C and that of the dolomite is 11.39 x 10^{-3} cal per cm/deg C, with standard deviations of 77 percent and 10 percent respectively of the means. These results, together with density measurements and chemical and mineralogical analyses, show that both the limestone and dolomite are remarkably uniform, from which it may be inferred that the sedimentation process and the succeeding metamorphic history were also very uniform.

Thermodynamic properties

R. A. Robie has made a critical compilation of entropies and heat contents, and calculated values of the heats and free energies of formation at 100-degree intervals to 1,000°C or higher for 58 minerals; he has also evaluated the fugacities and free energies at high pressures and temperatures for CO_2 and H_2O. These data are the first readily available for the rapid thermodynamic calculation of the temperature-pressure stability fields of certain minerals and for determining whether a particular chemical reaction will proceed or not.

PERMAFROST STUDIES

Permafrost studies, begun in 1945 following permafrost damage to the airfield at Northway, Alaska, have been extended over much of Alaska and to other parts of the Arctic. The primary objectives of these studies are to elucidate the general laws governing thermal phenomena in permafrost, to determine the areal extent of permanently frozen ground and its relation to various soil types, and to learn how permafrost behaves under varying engineering conditions (see p. A9 for a description of results that bear directly on engineering problems, and p. A58 for information on contraction cracks in permafrost). The work is being done in cooperation with the Office of Naval Research, Bureau of Yards and Docks, Bureau of Public Roads, Chemical Corps, Corps of Engineers, Alaska Railroad, Bureau of Reclamation, and other Federal and State agencies.

Areal differences in character of permafrost

In Alaska mapping of the general distribution and character of permafrost has delineated the boundaries between zones of continuous, discontinuous, and sporadic permafrost. Detailed mapping in the Fairbanks area (Williams, 1959; Williams, Péwé, and Paige, 1959) has shown the influence of surface drainage and sediment texture, as well as climate, on the depth to the permafrost table and on the distribution of ground ice masses.

In North Greenland the active zone has considerably greater bearing strength than the active zones in other permafrost regions (see p. A20). Preliminary studies indicate that the high bearing strength of the active zone in North Greenland is due to its uniformly low moisture content throughout the year (Davies, 1960a).

Interpretation of temperature data

The analysis of temperature data that Lachenbruch, Brewer, and others have been collecting for nearly ten years in a variety of environments in northern Alaska is now yielding significant information on the climatic history of that area. Because of the thermal disturbance caused by drilling—which usually raises temperature but sometimes lowers it—a correction must be applied to temperatures measured in drill holes. Although the change of temperature thus caused may take as long as 50 years to diminish to .01°C., one can now correct for it with such accuracy that residual secular changes in natural earth temperatures as small as .01°C. per year can be detected from measurements made a few years after drilling. Analysis of temperatures measured a few hundred feet beneath the surface near Point Barrow indicates that the temperature at the ground surface rose about 3°C. during the past 50 to 75 years (Lachenbruch and Brewer, 1959). As oceans and lakes have a pronounced thermal effect on permafrost, shoreline changes during the last several thousand years can be detected by analysis of temperatures measured at various depths near the present coast line. This method is being used at several arctic stations to learn the history of post-Pleistocene shoreline changes. Preliminary results obtained by Lachenbruch and Greene (*in* Kachadoorian and others, 1960) from temperatures in deep wells at Ogotoruk Creek (in the Chariot test site area—see p. A22) suggest that the permafrost is about 1,000 feet thick, that the climate has grown warmer in the past century, and that the sea has been transgressing on the land.

ROCK DEFORMATION

Observations on rock deformation accumulate continually as the result of geologic mapping, but investigations of the principles and mechanics of deformation that are also in progress are reported here (see p. A20 for a description of results of work related to engineering problems).

Contraction cracks

In analyzing the mechanics of contraction cracks, such as columnar basalt joints, mud-cracks, ice-wedge polygons, shrinkage cracks in concrete and ceramic glaze, A. H. Lachenbruch (Arts. 186 and 187) finds that their size can be explained in terms of stress-perturbation due to a single crack, and that they may be classified on the basis of whether or not most of the cracks intersect at right angles. Orthogonal polygons evidently evolve by progressive subdivision, and nonorthogonal ones by successive branching of rapidly propagated cracks. Hunt and Washburn (Art. 185) have found that contraction cracks, where they form on salt pans in Death Valley, yield patterned ground similar to that in frozen ground. While mapping the Late Triassic Watchung basalt fissure eruptives of New Jersey, G. T. Faust found that he could determine stratigraphic position within a flow from the character of the contraction joints. The joints are hexagonal in the upper part of a thick flow; those in the middle part are tetragonal; and those in the lower part are curved surfaces. In thin flows, the tetragonal joints are missing.

Tectonic fracturing and faulting

D. J. Varnes and S. P. Kanizay have found that certain geologic fracture patterns may be expressed in terms of trajectories of maximum shear stress predicted by the equations of plasticity. Using only the simplest formal theory of plasticity, that of von Mises, Varnes found that the theoretical and actual fault and vein patterns in the Silverton, Colo., mining district agree closely. In one instance, he found that the predicted position of a dike that curves through 154 degrees of strike in 7 miles was nowhere more than 400 yards away from its actual position, although he used only the two end points for control. This method of analysis appears to be worth testing in other areas.

Experiments at room temperature on the creep of Solenhofen limestone (Robertson, 1960) showed that the rate of creep decreased 100-fold when the hydrostatic pressure was increased from 1,000 to 2,000 bars. The experiments showed also that fracturing is one of the principal mechanisms of creep in limestone, although some fractures heal on unloading.

From an analysis of the main normal faults bounding tilted fault-block ranges, Moore (Art. 188) concludes that their surfaces are concave toward the down-thrown side, both in plan and section, and are therefore analogous to the spoon-shaped faults that bound many landslides.

Rock fragmentation and mixing due to volcanism and to strong shock

E. M. Shoemaker's mapping of serpentine-bearing diatremes of Arizona and Utah and their craters shows that these pipelike vents start with a fracture propagated by high-pressure fluid, are enlarged by high velocity flow of gases, solids and entrained wall-rock fragments, may be modified by spalling of the walls, and are ultimately filled with debris derived from above as well as below. Continued work on the origin of craters has led Shoemaker to detailed mapping of Meteor Crater in Arizona and to the application of modern theories of shock waves and hydrodynamic flow in analysis of the mechanics of impact (Shoemaker, 1959a, b, and Art. 192). He found that the observed structures and distribution of debris at Meteor Crater are consistent with those that would be produced by the impact of an iron meteorite about 80 feet in diameter travelling with a velocity of 15 kilometers per second at a high angle of incidence to the earth's surface and liberating energy equivalent to between 1.4 and 1.7 megatons of TNT. He finds (Art. 192) that mixing or scrambling of fragmented materials is a consequence of strong shock induced by artificial explosives and natural impact, and that the mixing motion occurs out to a sharply defined limit from the origin of the shock. The equation

$$R_{(\text{in feet})}=5.7W^{1/3}{}_{(\text{in tons of TNT equivalent})}$$

describes the relation between the limit of the domain of mixing and the energy released. Fragments of strongly shocked rock are dispersed in a breccia composed chiefly of rocks that have been subjected only to low shock pressures. At Meteor Crater the strongly shocked material may be recognized by its sintered or compressed and crushed condition. E. T. C. Chao, B. M. Madsen, and E. M. Shoemaker have found coesite, the high pressure polymorph of silica, to be generally present in fragments of strongly shocked Coconino sandstone, the principal rock-type present in the breccia. The occurrence of coesite at Meteor Crater, together with its absence from quartz crystals partially sintered by high pressure shock waves of very short duration, probably indicates that sluggish polymorphic transitions may occur a considerable distance behind the shock front in waves of longer duration.

PALEOMAGNETISM

From a review and evaluation of all published paleomagnetic data, supplemented by their own studies, Doell and Cox (Art. 193) conclude that paleomagnetic results from late Tertiary rocks strongly support the dynamo theory for the earth's magnetic field, and exclude extensive polar wandering during late Tertiary time. Although rocks of late Pleistocene age all show normal magnetization, numerous reversals in the Tertiary and early Pleistocene rocks suggest that the earth's field may have undergone at least a dozen complete reversals during the interval between middle Tertiary and middle Pleistocene time. Older rocks show less consistent results, but results obtained from the Permian, Carboniferous and Precambrian rocks show a high degree of consistency, and they indicate that the positions of the earth's magnetic pole differed significantly during those times from its present position. Their fundamental conclusion is that the available paleomagnetic data support the hypothesis that the magnetic pole has wandered during geologic time but that there is not yet conclusive evidence concerning continental drift.

Doell and Altenhofen (Art. 194) have designed and constructed a new Lambert equal-area projection, with an accuracy of one-tenth degree, useful in solving problems in spherical trigonometry encountered in paleomagnetic research and in other disciplines as well.

Results of other studies on paleomagnetism and remanent magnetism are described in connection with work on Snake River lava (p. A41) and various rocks in the Lake Superior region (p. A33 and Art. 93).

STUDIES OF THE THICKNESS AND COMPOSITION OF THE CRUST

The thickness of the earth's crust is being studied by gravity methods. Among the recent results of these studies is the discovery of a Bouguer anomaly low of more than 240 mgals (milligals) over the Sierra Nevada. This is interpreted as indicating the presence of a mountain root, although the anomaly may be partly due to the Sierra Nevada batholith, which is of lower density than the average crustal rock (Oliver, Art. 146). A regional gravity map of the Great Basin shows that the Bouguer anomalies are low where the regional topography is high, and vice versa, which indicates that the regional topographic features in the Great Basin are isotatically compensated (Mabey, Art. 130). Seismic refraction measurements along a line extending from the Nevada test site to Kingman, Arizona, suggest a crustal thickness of 31 km, if we assume a one layer crust, or 34 km for a two layer crust. These values are smaller, however, than those calculated from both gravity and surface wave studies in this area.

Over the Sacramento Valley, a high altitude aeromagnetic survey recorded a huge linear magnetic anomaly (1,000 gammas), and a large linear gravity anomaly has been found in the same area. These anomalies are both interpreted as effects of a large block of magnetic rocks 5 to 10 miles below the surface, probably intruded along a major fracture in the earth's crust. Similar broad aeromagnetic highs have been observed over the moderately deformed rocks of the Matanuska geosyncline in Alaska. In both areas relatively flat magnetic profiles are observed over adjacent belts of severely deformed sedimentary rocks of similar age. It is possible that the deeply buried magnetic rocks beneath the gently deformed areas are structurally more competent than the nonmagnetic rocks that apparently underlie the highly deformed belts. If so, this would account for the differences in the degree of deformation, for a competent igneous mass of the size believed to underlie the Matanuska geosyncline and Great Valley would have given them great structural stability (Grantz and Zietz, Art. 158).

Similar work indicates that the Appalachian Plateau of southeast Kentucky and central Tennessee is underlain by a block of dense, magnetic rock 100 miles wide, and 8,000 to 10,000 feet beneath the surface, and that the overlying Paleozoic rocks thicken to the east and north (King and Zietz, 1960).

MINERALOGY, GEOCHEMISTRY, AND PETROLOGY

Studies in the general field of mineralogy, geochemistry, and petrology are concerned with the description of new minerals; definition of the chemical and physical properties of minerals; experiments and observations on the mode of origin of minerals, rocks and ores; compilation of data on the distribution and abundance of the chemical elements in rocks and ores; experiments and observations on organic processes and materials that are of geologic importance; and observations and analysis of data on the distribution of the isotopes and nuclear properties of the elements and their meaning in terms of the age and origin of the containing minerals and rocks. Work in these fields is a fundamental part of many other Survey investigations and some of the new results of work in progress have already been discussed in connection with other problems (see especially the sections on mineral resources, geochemical prospecting, waste disposal, and natural distribution of elements as related to health). Other findings of wider application are described here.

MINERALOGY AND CRYSTAL CHEMISTRY

Mineralogic studies of valuable metalliferous and nonmetalliferous mineral deposits, and of minerals suitable for use in capture of radioactive wastes, have been described in previous sections of this review (see

p. A1–A12 and A24). Results of some of the studies of new minerals, synthesis of minerals, and of crystal chemistry are discussed here.

Description of new minerals and other mineralogic studies

The new basic mercuric sulfate schuetteite ($HgSO_4 \cdot HgO$) has been described by E. H. Bailey and others (1959), who found it in several quicksilver deposits in Nevada and at single localities in California, Oregon, and Idaho. It occurs on surfaces of cinnabar exposed to sunlight, where it probably formed through direct oxidation of cinnabar by oxygen-bearing surface water; it is also found on dumps of burnt ore, where it must have been formed from action of strongly acid sulfate waters on metallic mercury.

Charles Milton's completed study of kimseyite, a new zirconium garnet from carbonatite at Magnet Cove, Arkansas, has shown that its basic formula is $Ca_3Zr_2Al_2SiO_{12}$, a remarkable extension of known garnet structures.

In the course of a study of an unusual sample from the Wet Mountains thorium area, Colorado, submitted by M. R. Brock, F. G. Fisher found a new hydrated calcium-thorium phosphate mineral that is approximately the thorian analog of the newly described uranous phosphate, ningyoite. Like ningyoite it has a structure approaching that of rhabdophane at room temperature but changes to a monazite-type structure when heated above 900°C.

Several new minerals have been described from the borate districts in California. One of these is gowerite, a new calcium borate, $CaO \cdot 3B_2O_3 \cdot 5H_2O$, which Erd and others (1959) have shown to be formed by weathering of colemanite and priceite veins in basaltic rocks of the Furnace Creek formation. Additional new minerals that have been described by Survey workers are another hydrous calcium borate from the Death Valley region and a hydrous strontium borate $SrOB_2O_3 \cdot 4H_2O$ from the Kramer borate district. The rare borate minerals hydroboracite, inderite, and kurnakovite were found in the abandoned Eagle Borax Works deposit in Death Valley.

The new potassium uranyl silicate weeksite ($K_2(UO_2)_2(Si_2O_5)_3 \cdot 4H_2O$), described by Outerbridge and others (1960), was found at 10 localities in Utah, California, New Mexico, Wyoming, Pennsylvania, Texas, Arizona, and Mexico. It occurs in rhyolite and pegmatite and replaces pebbles in tuffaceous conglomerate.

Harry C. Starkey has shown that the true ion-exchange capacity of some zeolites is not determinable by the standard methods. Samples leached for over 100 days showed no indication of having reached an end point in the exchange reaction. It is possible, however, to speed the reaction by increasing the temperature.

Synthesis of minerals

Synthesis of minerals provides a means of solving many mineralogic, crystallographic, and geochemical problems. Robert Meyrowitz has synthesized excellent crystals of the uranyl carbonates liebigite, bayleyite (see Art. 201), andersonite, and swartzite for single crystal study and determined the conditions under which these compounds are formed. Synthetic and analytical studies of abernathyite, conducted by Frank Grimaldi and Robert Meyrowitz, determined its composition and helped in the study of its structure, described below. Synthesis of several of the California borate minerals by R. C. Erd afforded knowledge on chemical relations and provided material for X-ray, DTA, and other analytical studies.

Hans P. Eugster and his coworkers are studying the substitution of boron for tetrahedrally coordinated aluminum in silicates, and have synthesized boron analogs of analcite, sanadine, leucite, nepheline, kalsilite, and micas (Art. 202). This work has not only thrown light on the crystal chemical relations between these compounds, but may lead to some important new developments in ceramics.

Crystal chemistry

The principal investigations in progress in the field of crystal chemistry are aimed at the definition of the crystal structures and crystal chemistry of the borate, silicate, and phosphate minerals, and at the kinetic and thermodynamic relations between solid phases and the solutions from which these minerals are formed.

Analysis of the structure of a synthetic calcium borate by J. R. Clark and C. L. Christ have proved it to be a fifth member of the colemanite series, $2CaO \cdot 3B_2O_3 \cdot nH_2O$, with $n=1$. The crystals contain colemanite-like chains of B_3O_8 rings of two tetrahedra and one triangle joined laterally to form sheets. H. T. Evans and B. J. Skinner, from a structure study of β-spodumene, have defined the role of lithium in this unusual compound, and have shown that its base exchange properties and variable composition are due to the presence of channels and cavities. Similar information about the zeolite-like mineral bikitaite ($LiAlSi_2O_4 \cdot H_2O$) has resulted from the determination of its structure by D. E. Appleman. The crystal structure of väryneite, $MnBePO_4(OH)$, has been determined by M. E. Mrose and D. E. Appleman, and they have found that it contains tetrahedra of $BeO_3(OH)$ and chains of PO_4. These chains unexpectedly proved to be completely different from those in the isomorphous euclase, $AlBeSiO_4(OH)$, whose structure has also been accurately defined. The detailed arrangement of the layer structures of the autunite minerals has been revealed by Malcolm Ross and H. T. Evans in their determination of the structure of abernathyite, $KUO_2AsO_4 \cdot 3H_2O$. They found the interlayer cations to be distributed at random over fourfold sites with the water molecules.

A new classification of the hydrated borate minerals, prepared by C. L. Christ (1960), makes it possible to assign reasonable structural formulas to most of the borates whose structures are still unsolved. The scheme is founded on a set of crystal-chemical principles evolved from studies of crystal structures that govern the linkage of BO_4 tetrahedra and BO_3 triangles.

EXPERIMENTAL GEOCHEMISTRY

Research in the field of experimental geochemistry has been directed principally toward determining the conditions and mechanisms under which geologically significant chemical processes take place. Extensive studies are underway on: wet and dry silicate systems, solubility and reactions of minerals in hydrothermal solutions, and dry sulfide systems.

Silicate systems

From a study of the system $NaAlSi_3O_8$–$LiAlSO_4$–H_2O at 2000 bars David B. Stewart has shown that much natural eucryptite was probably formed by the replacement of spodumene by sodium rich solutions, and that the structural state of the albite associated with eucryptite is higher than expected. The $NaAlSi_3O_8$–$LiAlSiO_4$ join is of the "eutectic" type, with the four-phase point (albite-eucryptite-liquid-vapor) located at about 81 percent $NaAlSi_3O_8$, 19 percent $LiAlSiO_4$ and $733 \pm 3°C$.

Herbert R. Shaw has determined the four-phase point K-feldspar-quartz-liquid-vapor at 2000 bars H_2O pressure in the system $KAlSi_3O_8$–SiO_2–H_2O at K-feldspar 56 percent, SiO_2 44 percent, and $767° \pm 5°C$. The silicate liquid a few degrees above the four phase point contains about 5 weight percent H_2O.

David B. Stewart and Eugene H. Roseboom have shown from theoretical considerations of the final crystallization of ternary feldspar melts that slight changes in initial composition, temperature, degree of fractional crystallization, and water pressure can result in radically different textural relations in the fully crystallized product. Experimental investigations of these phenomena will prove difficult, however, because they involve a temperature range of only a few tens of degrees.

In an effort to interpret the genesis of welded tuffs, Robert L. Smith and Irving Friedman have measured the compaction rates of natural rhyolitic glasses as functions of water content (pressure of H_2O) and temperature and from these data they have calculated their viscosities. They have also found that the viscosity of the glass increases with time, possibly due to polymerization.

Reactions of minerals in hydrothermal solutions

George W. Morey and Robert O. Fournier have shown that the solubility of quartz in water at 15,000 psi decreases regularly from 330 ppm at 200°C. to about 70 ppm at 100°C. At still lower temperature extensive metastability exists, and at room temperature equilibrium is not obtained even after a year. The solubility of quartz below 220°C on the three phase curve (quartz-liquid-vapor) is greater than that determined by Kennedy; at 136°C it is 100 ppm.

Morey and Fournier have also investigated the reactions of some common silicates with water at 295°C and 2500 psi, and have found that microcline breaks down slowly to muscovite, albite alters more rapidly to paragonite, boemite, and an amorphous material; and that nepheline quickly breaks down to muscovite, boemite, and analcite. The total $Na_2O+K_2O+Al_2O_3+SiO_2$ in solution averages 167 ppm at pH 7.9 from microcline, 243 ppm at pH 7.9 from albite, and 440 ppm at pH 9.7 from nepheline.

The solubility of zincite at 25°C, and of brochantite, atacamite, and tenorite from 25 to 75°C, have been measured by Barton and Bethke (1960), who show that the solutions that deposit tenorite have a concentration of less than about $10^{-4.5}$ molar in Cu^{+2}.

Dry sulfide systems

Since the pioneer work of Kullerud appeared in 1953, several workers have helped refine the sphalerite geothermometer. The effect of FeS on the unit cell of sphalerite has been recalculated by Skinner, Barton, and Kullerud (1959), and Skinner and Barton have recently shown that errors of previous investigators were caused by the presence of ZnO in solid solution in the sphalerite. Skinner has also worked out linear-unit-cell versus mole-fraction curves for CdS and MnS in sphalerite and wurtzite. Skinner (1959) has completed four isotherms in the system MnS–FeS–ZnS and one in the system CdS–FeS–MnS, and shown that both Mn and Cd have small but measurable effects on the solubility of FeS in sphalerite, and that wurtzite is a stable phase down to low temperatures if large amounts of MnS are in solid solution. Preliminary studies of sphalerite in the Cu–Fe–Zn–S system by Priestley Toulmin indicate that the composition of sphalerite in equilibrium with pyrite and various copper-bearing sulfides lies principally along the ZnS–

FeS join, rather than along the ZnS–$CuFeS_2$ join, and also that the small amount of CuS (<5 mole percent at 600°–700°C) that can enter the sphalerite has little effect on the solubility of FeS. Barton has shown that the mole percent FeS in sphalerite in equilibrium with pyrite decreases about one order of magnitude when the activity of S_2 is increased by two orders of magnitude. The activity of S_2 is thus a much more important variable than temperature in determining the composition of sphalerite in pyrite-bearing assemblages. Kullerud's original solvus in the FeS–ZnS system has been verified independently by Skinner and by Kullerud (of the Geophysical Laboratory); and Barton and Kullerud have shown that this solvus applies to sphalerite-pyrrhotite assemblages below about 600°C.

Toulmin has shown that a complete solid solution series exists above 350°C between proustite and pyrargyrite, but his attempts to locate the solvus have been thwarted by failure to attain equilibrium at lower temperatures, even in runs of several months duration.

In investigating portions of the systems PbS–ZnS–ZnSe–PbSe, $CuFeS_{1.9}$–$CuFeSe_{1.9}$–PbSe–PbS, PbS–ZnS–CdS, and PbS–ZnS–MnS, Bethke and Barton (1959) have determined the distribution functions for Se, Cd and Mn between coexisting sphalerite and galena, and of Se between chalcopyrite and galena as functions of both temperature and pressure. Combination of the distribution of two minor elements between a pair of minerals therefore offers a very promising combined geothermometer-barometer. Concordant pressure–temperature values from the distribution of three or more elements provides a novel and widely applicable criterion of equilibrium between mineral pairs.

Barton and Toulmin (1959) have devised an electrum-tarnish method for the measurement of the activity (or chemical potential) of sulfur in laboratory sulfide systems, based on the thermodynamically well known systems Ag–S and Ag–Au. This work provides a powerful tool for determining the thermodynamic properties of many sulfides and it can also be used in developing several geothermometers.

GEOCHEMICAL DISTRIBUTION OF THE ELEMENTS

The distribution of elements and their role in geologic processes are being studied as a part of investigations in the fields of mineral resources, isotope geology, geochemical prospecting, public health (including radioactive waste disposal), experimental geochemistry, geochronology, and petrology; new findings in these fields are reported elsewhere. General investigations of the abundance and distribution of the elements are reported in the following sections on the revision of the "Data of Geochemistry," distribution of minor elements, and chemical composition of sedimentary rocks.

Revision of Clarke's "Data of Geochemistry"

Clarke's "Data of Geochemistry" is a critical compilation of data on the composition of the Earth, its rocks, minerals, waters and atmosphere, plus a summary of the data required to interpret the chemical processes that occur on and within the Earth. Good progress on the revision of this monograph was made during the year by the 44 authors, about half of whom are at universities and research institutions.

As part of this undertaking, Fleischer and Chao have made a critical study of published estimates of abundance of elements in the Earth's crust and have shown that most of them are actually based on the abundances in continental rocks. Because the ocean basins are composed essentially of basic rocks, the estimates usually cited for the Earth's crust are about an order of magnitude too low for elements such as nickel and chromium that are enriched in basalts, and about an order of magnitude too high for elements such as rubidium and barium, that are enriched in granitic rocks.

Chemical composition of sedimentary rocks

As a part of a project to compile the 20,000 to 25,000 analyses estimated to have been published on sedimentary rocks of the United States, T. P. Hill, M. S. Warner, and M. J. Horton have nearly completed a volume containing about 3,000 analyses of sedimentary rocks in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming.

The analyses in this compilation are classified by a ternary system, modified by W. W. Rubey from one proposed by Brian Mason in 1952, based upon the relative abundance of excess silica, a conventionalized clay molecule, and total carbonates. Analyses that contain less than 50 percent of these major components are grouped in special categories according to the predominant constituents, such as gypsum, phosphorite, and the like. Pertinent data, such as mineralogy and economic use to which the rock has been put, are given where available, and tables of means and standard deviations; triangular diagrams by lithologic character, classification group, and age; and cumulative frequency curves of each constituent are also included.

The assembled analyses may not adequately represent the various rock types and formations because the samples that have been analyzed were generally collected because of possible economic use of the rock.

The standard deviations of many constituents in a given rock type are large, indicating that averages of groups of analyses must be compared cautiously. Nevertheless, averages of some of the common rock types, in which large numbers of samples are available, probably approach meaningful values. The adjusted mean composition of shale, clay, and limestone are shown in the following tables, which illustrate also the kinds of summations being presented and the way in which they are computed.

Chemical composition of shale in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming

Constituents	Number of determinations	Mean of actual determinations	Standard deviation of actual determinations [1]	Mean with blanks counted as zero	Standard deviation with blanks counted as zero [1]	Adjusted mean [2]
	N	$\overline{X}_a$	s_a	$\overline{X}_b$	s_b	$\overline{X}_c$
SiO_2	226	56. 95	11. 14	56. 95	-----------	56. 95
Al_2O_3	219	16. 18	4. 48	15. 68	5. 23	15. 90
Fe_2O_3	203	4. 62	1. 87	4. 15	2. 26	4. 36
FeO	23	3. 13	2. 00	. 32	1. 14	1. 56
MgO	205	2. 27	2. 58	2. 06	2. 55	2. 15
CaO	224	4. 60	7. 81	4. 56	7. 79	4. 58
Na_2O	111	. 78	. 53	. 38	. 54	. 56
K_2O	124	2. 49	1. 25	1. 37	1. 55	1. 86
H_2O	23	5. 31	3. 24	. 54	1. 90	2. 64
TiO_2	100	. 99	. 64	. 44	. 65	. 68
P_2O_5	87	. 51	. 81	. 20	. 56	. 34
CO_2	13	8. 38	6. 91	. 48	2. 52	3. 96
SO_3	85	. 76	1. 02	. 29	. 72	. 49
Organic matter	16	8. 28	6. 66	. 59	2. 73	3. 97
Total	-----------	115. 25	-----------	88. 01	-----------	100. 00

[1] Calculated as: Standard deviation $=s=\left[\frac{1}{N(N-1)}\right]^{\frac{1}{2}}\cdot[N\Sigma X^2-(\Sigma X)^2]^{\frac{1}{2}}$

[2] Calculated as: Adjusted mean $=\overline{X}_c=\overline{X}_a-\left(\frac{\Sigma\overline{X}_a-100}{\Sigma\overline{X}_a-\Sigma\overline{X}_b}\right)\cdot(\overline{X}_a-\overline{X}_b)\cdot$ For example, the adjusted mean for K_2O is

$$\overline{X}_c=2.49-\left(\frac{115.25-100}{115.25-88.01}\right)(2.49-1.37)=186$$

Chemical composition of clay and limestone in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming

A. Clay (712 samples, but except for SiO_2, not all constituents were determined in all samples)

	$\overline{X}_a$	s_a	$\overline{X}_c$		$\overline{X}_a$	s_a	$\overline{X}_c$
SiO_2	65. 10	10. 58	65. 10	H_2O	7. 13	4. 18	3. 05
Al_2O_3	15. 51	5. 67	15. 33	TiO_2	. 87	. 48	. 67
Fe_2O_3	3. 60	1. 81	3. 53	P_2O_5	1. 78	2. 95	. 83
FeO	1. 47	1. 88	. 55	CO_2	7. 48	9. 90	3. 10
MgO	1. 40	1. 34	1. 18	SO_3	1. 05	1. 95	. 47
CaO	3. 32	6. 44	2. 85	Organic matter	2. 94	3. 18	1. 08
Na_2O	1. 50	1. 04	1. 03				
K_2O	1. 86	1. 01	1. 23	Total	115. 01	--------	100. 00

B. Limestone (751 samples, but except for CaO, not all constituents were determined in sll samples)

	$\overline{X}_a$	s_a	$\overline{X}_c$		$\overline{X}_a$	s_a	$\overline{X}_c$
SiO_2	6. 74	7. 14	6. 74	H_2O	1. 63	2. 69	1. 61
Al_2O_3	1. 49	1. 62	1. 48	TiO_2	. 21	. 18	. 20
Fe_2O_3	1. 21	1. 09	1. 20	P_2O_5	. 15	. 83	. 14
FeO	. 63	. 50	. 62	CO_2	36. 06	7. 94	35. 64
MgO	2. 22	3. 99	2. 22	SO_3	. 22	. 34	. 21
CaO	48. 19	7. 21	48. 19	Organic matter	1. 23	1. 53	1. 22
Na_2O	. 18	. 23	. 17				
K_2O	. 37	. 44	. 36	Total	100. 53	--------	100. 00

Two of the interesting relations that have emerged from this first compilation are: (a) cumulative frequency curves prepared for of each constituent suggest that major constituents tend to have a normal statistical distribution and minor constituents a log-normal distribution; and (b) with increasing geologic age the percentage of K_2O appears to increase in clays and shale but to decrease in carbonate rocks, suggesting that the potassium in interstitial waters may tend to become fixed in clay minerals with lapse of time.

Distribution of minor elements

During the past year the weighty mass of data on the uranium content of various magma series throughout the world obtained by Esper S. Larsen, Jr. and David Gottfried was augmented by analyses on many oceanic and continental basaltic suites. The results show that the oceanic basalts have consistently less uranium than their continental equivalents. The usual trend, in which uranium rises with SiO_2, is reversed in one such oceanic suite, the alkalic Honolulu volcanic series; this is the first such reversal encountered in the Survey's studies.

Results of several hundred precise thorium analyses by newly developed colorimetric methods do not bear out the generalization, recently published by Whitfield, Rogers, and Adams,[5] that the Th/U ratio rises with SiO_2 in granitic rocks as a result of loss of part of the uranium to late stage volatiles and solutions; instead the Th/U ratios in specific comagmatic series of known chemical composition, in contrast to the Th/U ratios on collected igneous rocks of diverse origins, average about 4.0 in all the differentiates. The one notable exception is the porphyry series in the Colorado Front Range studied by George Phair. In the Central City District a late-stage loss of uranium is indicated by the formation of pitchblende deposits. The late-stage differentiates (quartz bostonites) are remarkable for their high Th/U ratios (maximum 7.5), content of uranium (up to 130 ppm) and thorium (up to 300 ppm), and for their low content of CaO, (which is almost absent in some samples). They are about as close in composition to the experimental system Ab–Or–quartz studied by Tuttle and Bowen[6] as any rocks yet found in nature. But the high U and Th content of the residual magmas from which they crystallized is not an exotic late stage development; it was an end result of a fractionation process that can be traced backward in time through a series of earlier differentiates. These data for Th and U in large measure independently confirm the subdivision of the major Laramide petrographic provinces into subprovinces, and these in turn into separate centers of intrusion as delineated by plotting the major oxides on variation diagrams using the results of 70 standard rock analyses by rapid methods.

Phair and Gottfried have extended the Colorado Front Range studies to include the Boulder Creek intrusion, a small but complex Precambrian batholith, in order to assess the mobility of minor elements under conditions of (a) magmatic differentiation plus assimilation, (b) crushing and recrystallization, (c) hydrothermal alteration, and (d) reheating by later intrusions. Their data indicate that the general result of all post-solidification processes was to reduce the uranium content. Under conditions of crushing plus recrystallization, both uranium and lead are commonly removed from zircon, but the lead is removed more rapidly than the uranium, resulting in discrepant "low" ages. The low-age zircons from this batholith are commonly characterized by fresh, recrystallized rims.

A detailed survey of data on the abundance of zirconium in volcanic rocks made by Chao and Fleischer shows that within a given region, the zirconium content generally increases regularly with increasing content of silica and alkalies. There are marked regional variations, however, that are not yet explained. For example, basalts of Palau and Guam contain an average of 20 ppm Zr, those of the Aleutians and Japan about 50 ppm, and those of the Sierra Nevada of California close to 200 ppm Zr.

During the course of developing a method for analyzing zinc in silicate rocks, Rader and others (Art. 216), found that the zinc content of 159 samples of basalt from widely scattered areas ranges from 0.0048 to 0.018 percent and averages 0.0094 percent. Compared with other constituents, the zinc content of these basalts generally increases as the total iron increases and the silica decreases.

From analyses of minor metals in the rocks of the Pierre shale, Tourtelot and others (Art. 205) have found that bentonite seems to have the highest mean contents of zirconium and lead; shale and claystone with more than 1.0 percent organic carbon have the highest mean contents of vanadium, copper, arsenic, selenium, molybdenum, and uranium, and they tend to have the highest mean contents of boron, chromium and probably zinc. Marlstones have the highest mean contents of strontium and manganese. Zubovic and others (Art. 41; also p. A14) report that the elements most closely associated with carbonaceous matter in

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[5] Whitfield, J. M. Rogers, J. J. W., and Adams, J. A. S., 1959, The relationship between the petrology and the thorium and uranium contents of some granitic rocks: Geochim. et Cosmochim. Acta., vol. 17, nos. 3/4 p. 248–271.

[6] Tuttle, O. F., and Bowen, N. L., 1958, The origin of granite in the light of experimental studies: Geol. Soc. America Mem. 74.

coal are beryllium, boron, titanium, vanadium, and germanium.

ORGANIC GEOCHEMISTRY

Research in organic geochemistry, described here, relates to the structure and geochemical relations of naturally occurring organic substances, and to biogeochemical processes in isotope fractionation. Information on the minor metal content of certain fuels is discussed on pages A3 and A14, and the application of concentrator plants to studies of the incidence of disease and to geochemical prospecting are discussed on p. A25 and in Article 46, respectively.

Structure and geochemical relations of carbonaceous substances

A. M. Pommer and I. A. Breger have concluded from potentiometric titrations and infrared analyses of humic acid that in alkaline solution humic acid increases with time in its apparent equivalent weight while undergoing loss of carbonyl groups and conversion of aliphatic structures into polynuclear ring systems. Independent studies by I. A. Breger and by James Schopf indicate that much of the solid carbonaceous matter in Paleozoic and younger shales is similar to coal or lignite, but that one can distinguish between fractions of marine and nonmarine origin. Breger has also found that neutron irradiation induces the formation of free radicals and high reactivity in high-rank coals, and that it can convert humic acid in peat to a product resembling high-rank lignite. His studies of the structure of organic matter associated with Colorado Plateau uranium ores have led him to conclude that the ores are associated with humic substances related to coal rather than to oil. Infrared spectrophotometric analyses by F. D. Sisler of a piece of the Murray meteorite from the Smithsonian Institution collections indicate that it contains nitrile and other structurally "organic" components, as well as amorphous carbon.

Biogeochemical processes in isotope fractionation

The mechanisms by which hydrogen isotopes are fractionated by microorganisms and the divergent metabolic pathways of and biologic tolerances to protium, deuterium, and tritium are also being investigated by Sisler in an effort to evaluate ecologic and diagenetic effects and the possible significance of the process in producing heavy water. Laboratory cultures of a bacterium from the Bahama Banks generate protium-enriched gas during carbohydrate fermentation in normal media, and in those enriched in deuterium or tritium, but the fate of the heavy isotopes after fermentation is not yet clear. Experiments in progress with tritium-enriched glucose, in collaboration with Drs. Micah Krichevsky and Benjamin Prescott of the National Institutes of Health, suggest, however, that the heavy isotopes are bound within polysaccharide molecules and then excreted.

D. E. White (Art. 206), from his study of natural waters, infers a biogenic origin for the relatively high nitrogen and iodine content of connate and metamorphic waters and also for the high CO_2 content and relatively low C^{13}/C^{12} ratios of ground waters.

Equipment for mass spectrometric determination of C^{13}/C^{12} and O^{18}/O^{16} ratios has been installed under the direction of Irving Friedman and is now being used. Radiocarbon studies by Meyer Rubin show no detectable uptake of old carbonate by grasses growing on caliche and no evident fractionation of carbon isotopes in wood buried in an alkali soil.

PETROLOGY

Information on rock-forming processes and on the source of the materials of which rocks of various types are composed is gathered during most field and many laboratory investigations, and has already been discussed in several parts of this report (see especially the sections on mineral resources, regional geology and experimental petrology). Some studies, however, are concerned primarily with these subjects and are yielding results of wide application. These are reported in the following paragraphs.

Origin of granitic rocks

P. C. Bateman, L. D. Clark, N. K. Huber, J. G. Moore, and C. D. Rinehart have concluded that the granitic rocks of the Sierra Nevada are in discrete plutons, emplaced successively over a period of at least 12 million years. Many of the plutons are compositionally zoned, both laterally and concentrically, probably as a result of crystallization-differentiation. The plutons were emplaced by pushing the wall rocks aside and upward; piecemeal stoping was quantitatively unimportant. Granitization and assimilation effects are conspicuous, on a small scale, where granitic magma came in contact with mafic rocks, and the reactions that took place accord with Bowen's reaction series.

Toulmin (1959) has also called upon magmatic processes to explain the origin of a syenite body near Salem, Mass. He suggests that the syenite is an accumulated "shower" of feldspar crystals resulting from periodic release of volatiles from a granitic magma through volcanism. Crowder (1959), on the other hand, has concluded that a quartz-diorite complex in the Northern Cascade Mountains was formed by granitization of gneisses and schists. Locally the rocks were rendered plastic and mobile during granitization, and, in places, were fused to produce anatectic magmas that differentiated to form potassium-rich pegmatites and local granodiorite masses.

Origin of ultramafic rocks and related gabbros

E. D. Jackson has applied many of the techniques of sedimentary petrology to the layered rocks of the Ultramafic zone of the Stillwater complex, and has found that primary precipitate crystals are not only present in these rocks but that they obeyed the laws that control gravity stratification. From studies of the shape, distribution, and grain-size and size-distribution, orientation, and packing density of the settled crystals, and of the distribution and order of crystallization of the interprecipitate material, he has concluded that the rocks formed during crystallization of a single saturated basalt magma by accumulation of early crystal products on the floor of the magma chamber and that these crystals were enlarged or cemented after deposition by the magma from which they crystallized. Jackson believes that crystallization took place near the floor of the magma chamber, that the layered rocks directly reflect changing composition of the magma with time, and that the textures, mineral associations, and cyclical rock distributions in the ultramafic part of the complex can best be explained by a mechanism involving continuous but variable-depth convection that caused periodic refreshment of magma crystallizing in the lower part of the intrusion.

T. P. Thayer has compared the petrologic features of stratiform peridotite-gabbro complexes, like the Stillwater complex, with those of Alpine-type intrusions. He concludes that the stratiform complexes originated by crystallization of molten magma in place with little or no disturbance, whereas Alpine-type complexes were intruded as already differentiated crystal mushes and that mixing of gabbro and peridotite commonly occurred during emplacement.

Origin of welded tuffs

C. S. Ross and R. L. Smith have demonstrated the abundance of welded tuffs (ash flows) in the geologic record and the significance of fluids trapped within ash particles in maintaining an extensive subaerial flow of the dense pyroclastic clouds.

R. J. Roberts and D. W. Peterson have shown that two major types of welded tuffs—welded ash tuffs and welded crystal tuffs—can be distinguished on the basis of composition and texture. Eruptions yielding welded ash tuffs are generally characterized by higher silica content and higher volatile content than those yielding welded crystal tuffs. They conclude that the source magmas of the welded ash tuffs are more highly differentiated than those of the welded crystal tuffs.

Fluidity of lava

The problem of the fluidity of Precambrian basaltic lavas in the Lake Superior region has been considered by White (1960b), who has concluded that the typical thinning in the direction of flow, the absence of lava tunnels and of true aa, and the characteristic differentiation in the Keweenawan flood basalts can be ascribed to the great volume of the flows alone, rather than to greater fluidity of the basalts as has been suggested previously. Powers (Art. 136), on the other hand, has called attention to the exceptionally high fluidity of some alkalic lava in the Snake River plain.

Source of volcanic magmas

Several deductions have been made recently as to the source of specific volcanic magmas. In Bulletin 1028–H Snyder reported that chemical variations and extrusive sequences of the lavas of Little Sitkin Island in the Aleutian Islands of Alaska are inconsistent with the Bowen reaction series, and that they were produced by magmatic melting in a zone where continental and oceanic rocks had previously been mixed by tectonic processes. From the compositional trends and age relations of lavas on Semisopochnoi Island in the same area, Coats (1959) has suggested that, although the chemical trends can best be explained by differentiation, the differences between early and late extrusive rocks mean that magma was mixed with its earlier differentiates.

Peck (1960) believes that the Cenozoic volcanic rocks of the Cascade Range in Oregon were derived from five or six successive magmas, mostly of andesitic composition, that formed by partial or complete fusion of parts of the underlying crust during periods of crustal stress. Differentiation of these magmas, probably in large part by crystal fractionation, yielded volcanic rocks ranging from olivine basalt to rhyodacite. R. L. Smith, who studied the volcanic rocks of the Lava Mountains, Calif., found that earlier volcanic products in the area resulted from explosive activity, whereas the later ones were effusives. The frequency of eruption increased with time, but no systematic compositional change occurred. According to Smith, the volcanic magma probably formed by the complete melting of crustal quartz monzonitic rocks, and did not differentiate after eruptions began.

See page A47 for a description of recent observations at the Hawaiian Volcano Observatory.

Role of fluids in low-temperature alteration of volcanic glass

A. B. Gibbons, and others (Art. 214), from a study of volcanic rocks in southern Nevada, have suggested that mildly alkaline ground water moving through permeable tuff layers altered volcanic glass to zeolites at near-surface temperatures.

R. L. Smith and coworkers have recently shown that perlite, long considered a product of hydrothermal alteration of rhyolitic glass, is instead a surficial alteration produced by meteoric water; this conclusion is based partly on the similarity in isotopic composition of oxygen and hydrogen in the perlite to that of ground waters of the area in which it occurs.

Origin of propylitic alteration

In the San Juan Mountains, Colo., W. S. Burbank (Art. 6) has found that the propylitic or quartz-carbonate-chlorite type of alteration has affected many cubic miles of volcanic rocks throughout and beyond the Silverton caldera. Field relations and other data have led him to conclude that this type of alteration takes place after volcanic eruption has ceased as the result of evolution of gas, rich in CO_2, during crystallization and differentiation of deep-seated gabbroic and granodiorite magma. The process consists of (a) condensation of gases in locally adsorbed water films; (b) partial solution of silicate minerals by the condensates; (c) mixing of saturated condensates with other patches of liquid forced along by gas pressures; and (d) reaction in these mixtures causing precipitation of new minerals. Propylitized rocks are probably an arrested stage of this process; if it is long continued it probably forms carbonatized and chloritized rocks.

Metamorphism of maganese minerals

D. F. Hewett has found that the manganese orthosilicate, tephroite is widespread in manganese deposits in the Jurassic metavolcanic rocks of the western Sierra Nevada of California. Although tephroite is commonly regarded as of hydrothermal origin, Hewett believes that in the Sierra it is a product of the thermal metamorphism of original manganiferous carbonate in an environment of connate water.

Pavlides (Art. 211) has found that tightly folded beds in Aroostook County, Maine, containing braunite ($3Mn_2O_3 \cdot MnSiO_3$) and hematite, have been metamorphosed to magnetite-bearing rocks that contain no braunite. The recrystallization of the iron oxide and the migration of the manganese is most pronounced in areas of tight folds, which appear to have been local thermal nodes.

Steatitization as a product of regional metamorphism

In a recently completed study of the Vermont talc area, A. H. Chidester has found that the steatite was formed by regional metamorphism in two stages, both unrelated to earlier alteration of the ultramafic rocks to serpentine. In the first stage, serpentine was altered to talc-carbonate rock by addition of CO_2 and loss of H_2O. In the second, metamorphic differentiation in the contact zone between serpentinite and country rock formed steatite and "black wall" chlorite.

Origin of jadeite and rodingite in serpentine

Coleman (1959b) finds that jadeite in the California serpentine masses is stable in the glaucophane-schist facies and believes it formed by the desilication of quartz-keratophyres in a serpentine environment at pressures less than 5,000 bars and temperatures less than 300°C. In the San Francisco Bay area J. G. Schlocker has noted that alteration of sandstone to jadeite in the Franciscan formation is local, which indicates that the process was not controlled by conditions of regional extent, as formerly supposed. He also believes that the rodingites in the serpentines of the Franciscan formation are tectonic inclusions of calcium-enriched volcanic and other rocks (see Art. 145).

Migration of elements during metamorphism

The progressive metamorphism of basalt, graywacke, and siliceous magnesium limestone in the Adirondack Mountains of New York has been studied by Engel and Engel (Art. 212). They have found the metamorphism at 500° to 600°C was accompanied by emission of water and CO_2-rich fluids containing alkali silicates, Pb, Ba, and Mn.

A different group of elements—mainly Ca, Mg, Al, and Fe—migrated during the metamorphism of rocks in the Orofino area on the northwestern side of the Idaho batholith, according to Anna Hietanen-Makela. The temperatures attained during metamorphism there appear to have been 400° to 500°C. Mrs. Makela is using the aluminum silicates andalusite, kyanite, and sillimanite as a key to the temperature and pressure that prevailed during metamorphism.

Origin of evaporite deposits

E-an Zen (Art. 209) has applied the Gibbs Phase Rule to the precipitation of salts from a moving body of water and proposes that many mono-mineralic evaporite deposits form as a result of fractional crystallization from an ocean current (see also p. A8).

Petrographic studies by C. L. Jones of a core from salt in the Permian Hutchinson salt member of the Wellington formation in Reno County, Kansas, and of salts from several western fields show that magnesite and dolomite pervasively replace calcite, and that calcite is the main primary carbonate deposited in evaporite environments.

Transformation of aragonite mud to aphanitic limestone

Using electron microscopy techniques, J. C. Hathaway has shown that aragonite muds can be changed in a relatively short time to aphanitic limestone at low temperatures and pressures. In this transformation, the mud changes progressively from a mass of needle-shaped particles, to a mass of rounded and coalescing particles, to a final rock stage of mosaic texture and fracture surfaces typical of aphanitic limestone.

Origin of chert

The relation between type and chemical composition of chert has been studied by E. R. Cressman from data compiled from the literature. He plotted the SiO_2 content of each analysis against the ratio SiO_2/Al_2O_3, and compared the distribution of the plotted analyses with the lines representing the theoretical change in composition that would result from the addition of SiO_2 to the average pelagic clay, the average sandstone, and the average limestone. Analyses of radiolarian chert and shale fall in a well-defined trend that coincides with the line plotted from the composition of the average shale. Analyses of spicular cherts fall along the line plotted from the average sandstone. Analyses of chert nodules from limestone and dolomite are widely scattered, and all analyses fall to the left of the curve plotted from the composition of the average limestone; however, a curve representing the change in composition that would result from volume-for-volume replacement of calcite of the average limestone by quartz falls in the midst of the points, supporting the hypothesis that most nodular chert is of replacement origin.

From an analysis of the spatial relations of fossils and chert in the Redwall limestone (Early Mississippian) in Arizona, E. D. McKee (Art. 210) has suggested that layers containing abundant fossils were layers of maximum permeability and therefore especially susceptible to chertification. Dolomite in the same formation probably formed by the replacement of calcium carbonate on or beneath the sea floor before lithification, but a comparison of the preservation of fossils in dolomite and chert suggests that the chert formed before the dolomite.

ISOTOPE AND NUCLEAR STUDIES

Isotope and nuclear studies are being made in connection with many diverse problems, ranging from methods of ore finding to the study of paleotemperature. Only those studies having to do with the distribution of deuterium and tritium in natural fluids, measurement of alpha activity, and geochronology are described here. Results of other isotope and nuclear studies are discussed in the sections on beryllium (p. A8), uranium (p. A11), exploration methods (p. A15), and organic geochemistry (p. A65).

DEUTERIUM AND TRITIUM IN NATURAL FLUIDS

Differences in the isotopic composition of meteoric, connate, and thermal waters

Harmon Craig of the University of California, La Jolla, and Donald E. White have found that near Steamboat Springs, Nev., hot springs and surface waters differ significantly in D/H, O^{18}/O^{16} and C^{13}/C^{12} ratios, depending on details of origin and evaporational history (White and Craig, 1959). Preliminary data indicate that connate, magmatic, and metamorphic waters differ chemically (White, Art. 206) as well as isotopically (if both oxygen and hydrogen are considered together) from ordinary surface waters and that isotopic differences in surface waters are related to distance from the oceans, latitude, and evaporational history.[7]

Deuterium content of ocean and terrestrial waters

Preliminary results of a study of the deuterium variations in ocean waters being carried out by Irving Friedman, in cooperation with A. O. Redfield of Woods Hole Oceanographic Institution, indicate that in general the waters originating in the Antarctic contain as much as 1 percent less deuterium than other ocean waters, and can therefore be traced long distances northward.

Deuterium analyses of the surface waters of the United States show that the areas where deuterium is highest are mostly in the Gulf Coast region and in coastal Southern California (Friedman, unpublished data). Lower values are found further north on the Atlantic Coast and the Pacific Coast. The deuterium content decreases inland with increasing altitude and is especially low in the lee of high mountains.

In a study of the deuterium content of Arctic sea ice, Friedman, B. Schoen, and J. Harris found evidence for the existence of a layer of water derived from melted snow on the surface of parts of the Arctic ocean in summer.

Tritium and deuterium content of atmospheric hydrogen

The tritium and deuterium content of atmospheric hydrogen gas has been determined by Frederick Begemann of the Max-Planck Institut für Chemie, Mainz, Germany and Irving Friedman. Although the tritium is enriched by a factor of 10^4 to 10^5 over that in rain,

[7] Craig, Harmon, Boato, G., and White, D. E., 1956, Isotopic geochemistry of thermal waters: Proc. Second Conf. on Nuclear Processes in Geologic Settings, Pub. 400, Nat. Acad. Sci.-Natl. Research Council, p. 29–38.

the deuterium content is similar to that in rain. In samples collected in Buffalo, New York from January 1954 to October 1956, the tritium and deuterium contents show a linear relation to each other. A similar relation was found for samples collected in Germany by B. Gonsior, of the University of Heidelberg, who also made the tritium determinations on them.

Deuterium in liquid inclusions

Wayne Hall and Irving Friedman have found that the deuterium content of water extracted from liquid inclusions in minerals from the Cave-in-Rock fluorite district of southern Illinois show differences that are related to the paragenesis. Fluid inclusions from the early minerals have a deuterium content and salinity similar to that of local connate water. Fluid inclusions from later minerals are progressively depleted in deuterium.

MEASUREMENT OF ALPHA ACTIVITY

A method has been developed by A. Hoyte and F. Senftle for determining the absolute alpha activity of thick powdered mineral samples without using a standard sample. To measure alpha spectra with better resolution, Martinez and Senftle (1960) have studied the effect of crystal thickness and geometry on alpha particle resolution, using cesium iodide as a scintillator. As a result of these investigations, they have been able to obtain a resolution of 1.8 percent for Po^{210} alpha particles, which is considerably better than has ever been reported for crystal scintillators.

The effects of alpha-particle radiation damage on the magnetic properties of crystals has been critically examined by Senftle and Pankey, and they have devised a theoretical model which explains the heating curves for some uranium-bearing minerals such as zircon, coffinite, and uraninite. A new method of age determination based on this work has been outlined (see p. A70), and efforts are currently being made to develop its details.

GEOCHRONOLOGY

Many age determinations based on C^{14}, potassium-argon, strontium-rubidium, and uranium-lead methods have been made by the Geological Survey to help in solving geologic problems. Most of the recent age determinations that bear mainly on problems of local or regional geology are discussed in other parts of this report, but some results of wider interest are reported here, along with work on new methods.

Refinement of the geologic time scale

The age of mica from several stratigraphically well-defined rocks that could serve as tie points in the geologic time scale was measured by Henry Faul and Herman Thomas by potassium-argon and strontium-rubidium methods. The results are listed here in order of increasing age:

	Millions of years
Middle or late Eocene (Rocky Boy Stock, Bearpaw Mtns. Montana)	50
Early Permian or later (Oslo region)	260
Post-Westphalian (younger than Late Carboniferous) (Dartmoor granite, Cornwall)	290
Dinantian, pre-Visean (early Carboniferous) (Vosges granites, France)	320
Late Devonian (Chattanooga shale, Tennessee)	340–385
Post-Middle Devonian (Hog Island, Jackman, Maine)	360
Between Late Silurian, Late Devonian (Calais granite of Foyles and Richardson, 1929, Maine)	405
Middle Ordovician (Alabama bentonites)	420–450

No useful tie points are yet known below the Middle Ordovician, so the length of Cambrian time can only be surmised; the above results indicate, however, that the total length of time since the Precambrian is greater than previously thought.

Some zircon concentrates from stratigraphically closely bracketed rocks were studied by Thomas Stern and Harry Rose, who obtained the following results:

Locality and sample	*α/mg-hr*	Pb(*ppm*)	*Age (millions of years)*	*Geologic age given in the literature*
San Vincente, Baja California, SV–1	152	6.1 (6.0, 6.2)	100±10	Early Late Cretaceous (post-Albian pre-Maestrichtian).
Talkeetna Mountains Alaska, GG–1	68	3.4 (3.4, 3.4)	125±15	Post late Early Jurassic, pre-middle Late Jurassic.
Talkeetna Mountains Alaska, GG–2	103	5.7 (6.1, 5.3)	135±15	Post late Early Jurassic, pre-middle Late Jurassic.
Martinsburg shale, near Strasburg, Va. VA–2	144	24.5 (24.5, 24.5)	410±45	Middle and Late Ordovician.
Martinsburg shale, near Strasburg, Va. FMB–1.	137	23.5	410±45	Middle and Late Ordovician.

The above ages were calculated from the formulas and constants given by Gottfried and others (1959, p. 16–19). The errors given above are due only to uncertainties in analytical techniques. These analyses indicate that the lead-alpha age method yields results which are consistent with the lengthened time scale suggested by other workers.

Age of some uranium ores

According to Stieff and Stern the Pb/U ratios of uraninite samples from the Urgeiriça and Lenteiros mines in Portugal indicate that the age of the ore in both mines is about 83±8 m.y.

Algebraic and graphical methods have been developed for evaluating discordant lead-uranium ages (Stern and others, Art. 23). Applying these methods, Stern and others have concluded that the uraium deposits in Carbon County, Pennsylvania, were emplaced during Late Jurassic or Early Cretaceous time.

A geochronologic method based on magnetic properties of crystals damaged by radiation

Sentfle and Pankey have found that the iron impurity in crystals damaged by natural radiation is in a reduced nonmagnetic state in the damaged regions. On heating for a limited time in an oxygen deficient atmosphere the crystals at first become magnetic due to diffusion of oxygen into the damaged regions and the subsequent oxidation of the iron to magnetite (Fe_3O_4). On further heating the crystals again become non-magnetic due to the oxidation of the Fe_3O_4 to non-magnetic α hematite (Fe_2O_3). The maximum magnetization measured during the heating cycle is proportional to the number of Fe_3O_4 molecules formed, and this in turn is related to the total radiation damage. As the damage is a function of the age of the crystal, the technique promises to be useful in age determinations. Preliminary measurements have yielded ages that in most cases are close to the age as measured by isotopic methods.

A geochemical method for dating obsidian artifacts

Friedman and Smith (1960) have developed a new dating technique that depends upon the rate of diffusion of water from the atmosphere into freshly worked obsidian artifacts. The useful range of the method is from about 100 years well into the Pleistocene. The age of the obsidian is related to the thickness of the hydrated layer, as measured with the petrographic microscope, and seems to follow the diffusion law $x = k\sqrt{t}$, where x = thickness of the hydrated layer, t = time, and k is a constant which depends on the temperature of hydration and the composition of the glass, but seems to be relatively independent of the humidity of the environment.

Carbon-14 dates applied to the study of Pleistocene glaciation

Carbon-14 measurements on samples from many parts of the world show that glaciations were synchronous in both the northern and southern hemispheres. According to Meyer Rubin, this indicates that glacial pulsations were not caused by local changes in the pattern of precipitation, as has been proposed recently by Ewing and others, but resulted instead from world-wide cooling.

The carbon-14 data have confirmed the concept that changes of sea level during the Pleistocene corresponded to glacial pulsations. They have also demonstrated the rapidity with which climatic changes took place, and have shown that the time since the last continental glaciation was only about half as long as previously supposed.

ANALYTICAL AND OTHER LABORATORY TECHNIQUES

Much of the research already discussed in this report is an outgrowth of or depends in one way or another on chemical, spectrographic, and other analyses performed by the Survey's analytical laboratories, so that a large part of the results of their work has already been described. In addition to making such analyses, however, the laboratories also investigate new methods of analysis and other laboratory techniques so as to improve their accuracy, precision, and efficiency. Methods applicable to geochemical prospecting and nuclear studies are described on pages A14 and A16. Some of the other important results of this research are summarized in the sections that follow on analytical chemistry, spectroscopy, and mineralogic techniques.

ANALYTICAL CHEMISTRY

Zirconium in small amounts

The properties of the dye 5-sulfonic acid-2-hydroxbenzene-azo resorcinol and its use as a reagent for the determination of microgram amounts of zirconium have been studied by Mary H. Fletcher. The four acidic groups of this dye dissociate in solution to give equilibrium mixtures of four anionic species each having a characteristic absorption spectrum. Spectral data were used to deduce the dissociation constants of these species, and the same approach was used to determine the equilibrium constants of the two zirconium complexes that this dye forms. It was found that zirconium in pure solution can be determined over a wide range of conditions, which gives great flexibility in overcoming interference. The methods used in this study should be useful in determining the components of other multi-component colored systems.

Niobium and tantalum

Grimaldi and Schnepfe (1959) have found that selenous acid can be used to separate Ta and Nb from relatively large amounts of the elements usually associated with them in their ores, and to determine total Ta and Nb or either element. The procedure has been used for analyses of 50 to 75 mg samples of columbite and tantalite ores in which the Ta and Nb are present in amounts ranging from 0.2 to 30 mg. Grimaldi (1960) has also designed a method for determining the niobium content of rocks in the parts per million range. Interfering elements, such as Re, W, Mo, and V, are separated from Nb by simple sodium hydroxide fusion and leach. The determination is completed spectrophotometrically by a modified thiocyanate procedure.

Flame photometry

Two approaches were studied to overcome matrix effects in flame photometry. In one (Grimaldi, Art. 225) matrix effects are largely overcome by dilution of the sample; those that remain are corrected for by an addition technique. In the other approach, an extraneous element is added to release the normal emission of a given element. Releasing agents and techniques were examined by J. I. Dinnin, who found that Sr, La, Nd, Sm, and Y completely release Ca from quenching by Al, SO_4^{-2}, and PO_4^{-2}, while Mg, Be, Ba, and Sc do so to a large extent. The use of praseodymium as a releasing agent permits the determination of calcium in chromite, hitherto impossible to do by flame photometry.

Analysis of liquid inclusions

Methods have been devised by B. L. Ingram for determining microgram amounts of Cl^-, SO_4^{-2}, and Mg in liquid inclusions. Chloride is determined indirectly through its release of thiocyanate ion from mercuric thiocyanate, the released thiocyanate being converted to a colored ferric thiocyanate complex. Magnesium is directly determined spectrophotometrically with Magnon. Sulfate is reduced to sulfide with a mixture of hydriodic, hypophosphorous, and formic acids, and determined spectrophotometrically as methylene blue.

Fluorine in phosphate rock and chlorine in silicate rock

A rapid method for the determination of fluorine in phosphate rock has been described by Shapiro (1960). The sample is dissolved in dilute nitric acid, the solution is passed through a cation-exchange resin column, and the fluorine in the effluent is determined by its bleaching action on the red aluminum-alizarin complex. A method for determining chlorine in silicate rock by titration with mercuric nitrate, using sodium nitroprusside as the indicator, has been devised by Peck and Tomasi (1959).

Small amounts of magnesium

Investigations of new methods for determining small amounts of magnesium have proved fruitful. Bissalicylidene-ethylenediamine makes it possible to determine magnesium photometrically or fluorimetrically (Cuttitta and White, 1959; White and Cuttitta, 1959); and by using thiazole yellow, it is possible to determine it photometrically in rocks, without prior separations (Shapiro, 1959).

Uranium

Stevens and others (1959) have developed an automatic machine for preparing reproducible phosphors in the fluorimetric determination of uranium.

Analysis of chromite

Improved procedures were developed or adapted for determining Al, Ca, Si, total Fe, Cr, and ferrous iron in chromite. To determine total iron, for example, the chromite is dissolved in a mixture of phosphoric and sulfuric acids; the iron is then reduced with a silver reductor, and finally determined by titration with dichromate (Dinnin, Art. 215).

Ferrous iron

Two new methods for determining ferrous iron in rocks and minerals have been developed. In one, the sample is decomposed with a mixture of hydrofluoric and sulfuric acids in the presence of dichromate in excess over the ferrous iron; the excess dichromate is then titrated with standard ferrous sulfate (Reichen, L. E., and Fahey, J. J., written communication). In the other, the sample is decomposed with the same acids, but in the presence of an excess of o-phenanthroline to complex the released ferrous iron; the determination is then completed colorimetrically by measuring the absorbance of the orthophenanthroline-ferrous complex (Shapiro, Art. 226). Both methods avoid errors in conventional procedures resulting from air oxidation of ferrous iron during decomposition of the sample.

Zinc in silicate rocks

A spectrophotometric method for determining small amounts of zinc in silicate rocks has been devised by Rader and others (Art. 216); zinc is isolated by anion exchange and carbamate extraction, and then measured colorimetrically with zincon.

Combined gravimetric and spectrographic analysis of silicates

A method that combines gravimetric and spectrographic procedures for the analysis of silicate rocks and minerals has been studied by Stevens and others (Art. 228). Its essential features are that major constituents are chemically separated and weighed; all precipitates and residues are then analyzed spectrographically to make corrections for gains, losses, and impurities, and to determine minor constituents. Although the method has promising advantages over conventional procedures, it is so time consuming that it is suitable only for special analyses that require unusual accuracy and precision.

Accuracy and precision of silicate analyses

A second report on the accuracy and precision of silicate analyses has been prepared by Stevens, Niles, Chodos, Filby, Leininger, Flanagan, Ahrens, and Fleischer (1960) as Bulletin 1113. It summarizes the results of over 30 new analyses of samples G–1 (granite) and W–1 (diabase) from laboratories throughout the world, discusses the limitations of standard rock analysis, and points out areas where improved methods are needed. The study indicates that, of the procedures in use, those for determining silica and alumina are least accurate; the results for SiO_2 are generally too low, and those for Al_2O_3 are generally too high.

SPECTROSCOPY

Concentration of rhenium for analysis

As a part of a study of the distribution of rhenium, Myers and others (Art. 20) extended the limit of detection of water-soluble rhenium from about 50 ppm to about 0.1 ppm by employing a concentration technique. In this method, rhenium is leached from a 50 gram sample with distilled water; the dried extract is then added to a definite proportion of powdered quartz and analyzed spectrochemically by means of the d-c carbon arc.

Determination of lead in zircon

A synthetic zircon-baddeleyite-glass mixture containing lead has been prepared by H. Rose and T. Stern for determining lead (1 to 500 ppm) in zircon for lead-alpha age measurements by a d-c arc technique. Fifteen milligram samples are mixed with 35 mg of sodium carbonate and arced at 15 amps for 90 seconds. Analysis of 20 zircons indicates an overall 5 percent average deviation from isotope-dilution and chemical values. The new standard and procedure replaces the opal-glass standard previously used, which was shown to be inadequate by comparison of analyses made by independent methods.

Use of special standards in spectrochemical analysis

Because of the large variety of materials submitted for analysis, special standards are frequently required for quantitative measurement of various elements. For example, during the analysis of some water residues, Mrs. N. Sheffey found that the analytical lines for Fe, Al, Zn, V, and Cr were depressed by high sulfate ion concentrations. This difficulty was overcome by diluting the samples with the same matrix as used for the standards.

Use of gas jet in reducing cyanogen band interference

A relatively simple gas jet surrounding the carbon arc used for spectrochemical analysis has been found effective in reducing the cyanogen bands (Annell and Helz, Art. 227). Argon flowing at a rate of 16 cu ft hr and mixing with oxygen at 4 cu ft hr, was found most suitable for suppressing the bands, stabilizing the arc, reducing sample consumption, and intensifying lines. Controlling the arc atmosphere in this manner makes it possible to analyze several elements that have diagnostic lines in the cyanogen region, such as Ce, La, Sm, Pr, Nd, Eu, Tm, Tl, W, Ru, and Ti.

A constant feed direct-current arc

A method has also been developed by Annell and Helz for continuously vaporizing successive increments of powdered rock and mineral samples into a 10-ampere d-c arc. In this procedure graphite electrodes, 0.092 inch in outer diameter and containing a bore 1.5 inches deep and 0.046 inches in diameter, are used as sample anodes. Elements such as Ti, Al, Si, Cu, Ga, As, and Pb are concomitantly vaporized and excited by gradually moving the electrode into the arc through a channel in a brass, water-cooled collar. A controlled atmosphere, consisting of a mixture of argon, flowing at the rate of 14 cu ft hr, and oxygen, flowing 7 cu ft hr, suppresses cyanogen band interference in the spectra and stabilizes the arc. Graphite and lithium tetraborate are mixed with the powdered rock samples to obtain an optimum rate of burning in the arc, selective volatilization, enhancement of desirable lines, and minimum matrix interference.

Development and use of the electron microprobe analyzer

The electron microprobe analyzer, designed by Isidore Adler, is now completed and in operation. This device uses a focused beam of electrons to excite X-rays from samples of the order of several cubic microns in volume. The resulting X-rays may then be analyzed either to identify the elements in the microscopic phase or to give the actual concentration. The sample to be analyzed is located by means of a reflecting-type microscope that is coaxial with the objective magnetic lens and is in the vacuum system. This microscope has a reflecting objective, perforated to permit the electron beam to reach the sample. The X-rays are analyzed by means of two X-ray spectrographs mounted in vacuum chambers.

The electron microprobe is now being used for studying the distribution of minor elements in galena and sphalerite. A tentative procedure has been established for mounting small grains in clear cold-setting plastic. By using small brass rings ⅛-inch in diameter, as many as 12 different specimens can be mounted in a one inch disk and analyzed without opening the vacuum sample chamber. The cold-setting plastic, moreover, quickly forms a small dark spot where bombarded by the electron beam, which makes it possible to position the desired area readily.

Techniques have been worked out for analyzing nonconducting mineral grains by vacuum-coating them with optically transparent films of aluminum in order to make the surface electrically and thermally conducting. This is necessary in order to minimize surface charging and heating.

X-ray fluorescence analysis of sphalerite

An X-ray fluorescence method has been developed by Adler for determining minor constituents in sphalerites when gross samples are available. Results for cadmium, iron, and manganese agree with the chemical figures to within about 5 percent of the amount present.

MINERALOGIC AND PETROGRAPHIC TECHNIQUES

New techniques and tools in microscopy

Wilcox (1959 b, c) has designed two devices for optical determination on single mineral grains. One is a rugged spindle stage, attached to a petrographic microscope, on which crystals can be mounted and their principal indices of refraction and optical sign determined by rotating the spindle. He has also designed a simplified universal stage accessory for determining the three principal indices of refraction in biaxial crystals. B. F. Leonard, III has perfected a method for quantitatively measuring the reflectivity of opaque minerals with a Hallimond visual microphotometer. New immersion liquids with indices of refraction between 1.7 and 2.1 have been developed by R. Meyrowitz and H. Westley.

Mineral separation methods

The principle of asymmetric vibration has been adapted to separate micas and to serve as an improved feeding device for the Frantz separator (Faul and Davis, 1959). Frost (1959) has developed a constant flow elutriating tube for separating high density sulfides from light silicate gangue. Meyrowitz and others (1959) have found that dimethyl sulfoxide is a more stable diluent for bromoform than acetone and F. Cuttitta, R. Meyrowitz, B. Levin, and N. Hickling report that dimethyl-formamide shows promise as a diluent for bromoform or methylene iodide.

Staining and autoradiographic methods

Staining techniques for the modal analysis of feldspars in thin sections, grain mounts, and polished sections have been improved by E. H. Bailey and R. E. Stevens; they stain potassium feldspar yellow with cobaltinitrite and plagioclase red with barium rhodizonate. R. F. Gantier and J. A. Thomas have examined many dyes and reagents for staining feldspars and have found that malachite green, methyl red, and methyl violet are the most satisfactory. In a different approach to the same problem, Wayne Mountjoy and L. B. Riley have used the radioactivity of potassium to determine the distribution of potassium feldspar by means of photographic prints.

Methods for studying liquid inclusions

Apparatus and techniques have been developed by E. W. Roedder and Irving Friedman for vacuum crushing, extraction, and limited analysis of the soluble salts in solution from single selected fluid inclusions less than a millimeter in diameter. With slightly larger inclusions, H_2O, CO_2, H/D isotope ratio, and concentration of dissolved salts can also be determined. A new and improved heating and cooling microscope stage has been developed for studies of liquid-gas inclusions, which permits determination of the temperature of filling on heating, and depression of the freezing point on cooling. The freezing point may be used to estimate the concentration of soluble salts in a single fluid inclusion whose volume may be as small as a billionth of a milliliter.

Methods in experimental geochemistry

E. Roseboom has achieved promising results toward solving the difficult experimental problem of measuring total pressure of very reactive sulfur- and arsenic-bearing systems; he uses low-melting alkali halides as manometer liquids.

Brian J. Skinner has put into operation an inexpensive mullite stage for the X-ray diffractometer that allows measurements to be made at temperatures up to 1400°C under vacuum or controlled atmospheres.

Gulbrandsen (Art. 230) has found that the solubility depressant effect of ethyl alcohol on saline solutions is an effective means of controlling and studying the precipitation of evaporites.

GEOLOGIC DIVISION OFFICES

MAIN CENTERS

U.S. Geological Survey, Main Office, General Services Building, F St., between 18th and 19th Streets, N.W., Washington 25, D.C., Republic 7-1820.

U.S. Geological Survey, Rocky Mountain Center, Federal Center, Denver 2, Colorado, Belmont 3-3611.

U.S. Geological Survey, Pacific Coast Center, 345 Middlefield Road, Menlo Park, California, Davenport 5-6761.

FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included]

Location	*Geologist in charge and telephone number*	*Address*
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Arizona, Globe	N. P. Peterson (964)	P.O. Box 1211.
California, Los Angeles	John T. McGill (Granite 3-0971, ext. 547)	Geology Building, University of California.
Hawaii, Hawaii National Park	K. J. Murata	Hawaiian Volcano Observatory.
Hawaii, Honolulu	Charles G. Johnson (81011 ext. 66-3161)	District Building 96, Fort Armstrong.
Kansas, Lawrence	Wm. D. Johnson, Jr. (Viking 3-2700)	c/o State Geological Survey, Lindley Hall, University of Kansas.
Maryland, Beltsville	Allen V. Heyl (Tower 9-6430, ext. 468)	U.S. Geological Survey, Department of Agriculture Research Center Building.
Massachusetts, Boston	L. W. Currier (Kenmore 6-1444)	270 Dartmouth Street, Room 1.
Michigan, Iron Mountain	K. L. Wier (1736)	P.O. Box 45.
Mississippi, Jackson	Paul L. Applin (Fleetwood 5-3223)	1202½ North State Street.
New Mexico	Charles B. Read (Chapel 7-0311, ext. 483)	P.O. Box 4083, Station A, Geology Building, University of New Mexico.
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Puerto Rico, Roosevelt	Watson H. Monroe (San Juan 6-5340)	P.O. Box 803.
Tennessee, Knoxville	R. A. Laurence (2-7787)	11 Post Office Building.
Utah, Salt Lake City	Lowell S. Hilpert (Empire 4-2552)	506 Federal Building.
Vermont, Montpelier	W. M. Cady (Capitol 3-5311)	43 Liberty Street.
Washington, Spokane	A. E. Weissenborn (Temple 8-2084)	South 157 Howard Street.
Wisconsin, Madison	C. E. Dutton (Alpine 5-3371, ext. 2128)	222 Science Hall, University of Wisconsin.
Wyoming, Laramie	W. R. Keefer (Franklin 5-4495)	Geology Hall, University of Wyoming.

GEOLOGIC DIVISION OFFICES

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Brazil, Porto Alegre	A. J. Bodenlos	c/o American Embassy, APO 676, New York, New York.
Brazil, Rio de Janeiro	C. T. Pierson	U.S. Geological Survey, c/o American Embassy, APO 676, New York, New York.
Brazil, Rio de Janeiro	A. J. Bodenlos	U.S. Geological Survey, c/o American Embassy, APO 676, New York, New York.
Brazil, Sao Paulo	A. J. Bodenlos	U.S. Geological Survey, c/o American Consulate General S.P., APO 676, New York, New York.
Chile, Santiago	W. D. Carter	U.S. Geological Survey, c/o American Embassy, Santiago, Chile.
India, Calcutta	Lawrence Blade	U.S. Geological Survey, c/o American Consulate General, 5/1 Harrington Street, Calcutta 16, India.
Indonesia, Bandung	David A. Andrews	U.S. Geological Survey, USOM to Indonesia, c/o American Embassy, Djakarta, Indonesia.
Libya, Tripoli	Gus Goudarzi	U.S. Geological Survey, USOM, APO 231, c/o Postmaster, New York, New York.
Mexico, Mexico, D. F.	Ralph Miller	U.S. Geological Survey, USOM American Embassy, Mexico, D. F., Mexico.
Pakistan, Quetta	John A. Reinemund	U.S. Geological Survey, USOM American Embassy, APO 271, New York, New York.
Philippines, Manila	Joseph F. Harrington	U.S. Geological Survey, c/o American Embassy, APO 928, San Francisco, California.
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Turkey, Istanbul	Quentin D. Singewald	U.S. Geological Survey/ICA, c/o American Embassy, APO 380, New York, New York.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC DIVISION DURING FISCAL YEAR 1960

Investigations in progress in the Geologic Division during fiscal year 1960 are listed below, together with the names and headquarters of the individuals in charge of each. Not all of the investigations listed were active during fiscal year 1960; for example, many are completed except for publication of final reports, and some have been temporarily recessed. Headquarters for major offices are indicated by the initials (W) for Washington, D.C., (D) for Denver, Colo., and (M) for Menlo Park, Calif. Headquarters in all other cities are indicated by name; see list of offices on preceding pages for addresses.

Projects that include a significant element of geologic mapping are indicated by asterisks. One asterisk (*) indicates projects that involve geologic mapping at a scale of a mile to the inch or larger; two asterisks (**) indicate projects that involve geologic mapping at a scale smaller than a mile to the inch.

Because many of those interested in work in progress are concerned with a specific political area, the investigations are classified by State or similar unit, and titles are repeated as necessary to show work in progress in a given area (investigations, however, that deal with more than four States are listed only under the heading "Studies of large regions of the United States"). Investigations concerned with mineral resources, engineering problems, methods, or geologic processes are listed under geographic headings if they involve a specific area, but they are also listed under topical headings. They are not repeated within the topical groups, however, even though they may deal with more than one subject. The assignment of investigations by subject has been determined by the dominant activity or objective of each. Titles of these investigations are listed only under the topic that represents the dominant activity or objective of each; individual titles are not repeated under other topical headings, even though the investigation may deal with more than one subject. The reader interested in work in progress in, for example, mineralogy, will wish to examine titles of investigations underway in related fields, such as experimental geochemistry, waste disposal, and mineral resource investigations.

REGIONAL INVESTIGATIONS

Large regions of the United States:

- Geologic map of the United States
  - P. B. King (M)
- Paleotectonic maps of the Pennsylvanian and Permian
  - E. D. McKee (D)
- Synthesis of geologic data on Atlantic Coastal Plain and Continental Shelf
  - J. E. Johnston (W)
- Coal fields of the United States
  - J. Trumbull (W)
- Granites and related rocks of the Southeastern States, with emphasis on monazite and xenotime
  - J. B. Mertie, Jr. (W)
- Igneous rocks of Southeastern United States
  - C. Milton (W)
- Geology of the Piedmont region of the Southeastern States, with emphasis on the origin and distribution of monazite
  - W. C. Overstreet (W)
- Investigation of sea-level changes in New England
  - M. Rubin (W)
- Lower Paleozoic stratigraphic paleontology, Eastern United States
  - R. B. Neuman (W)

Large regions of the United States—Continued

- Ordovician stratigraphic paleontology of the Great Basin and Rocky Mountains
  - R. J. Ross, Jr. (D)
- Silurian and Devonian stratigraphic paleontology of the Great Basin and Pacific Coast
  - C. W. Merriam (W)
- Midcontinent Devonian investigations
  - E. R. Landis (D)
- Upper Paleozoic stratigraphic paleontology, Western United States and Alaska
  - J. T. Dutro, Jr. (W)
- Mesozoic stratigraphic paleontology, Pacific coast
  - D. L. Jones (M)
- Mesozoic stratigraphic paleontology, Atlantic and Gulf coasts
  - N. F. Sohl (W)
- Cordilleran Triassic stratigraphy
  - N. J. Silberling (M)
- Jurassic stratigraphic paleontology of North America
  - R. W. Imlay (W)
- Cretaceous stratigraphy and paleontology, western interior United States
  - W. A. Cobban (D)

Large regions of the United States—Continued
- Middle and Late Tertiary history of parts of the Northern Rocky Mountains and Great Plains
  - N. M. Denson (D)
- Gravity map of the United States
  - H. R. Joesting (W)
- Cross-country aeromagnetic profiles
  - E. R. King (W)
- Aeromagnetic profiles over the Atlantic Continental Shelf and Slope
  - E. R. King (W)
- Geophysical studies of Appalachian structure
  - E. R. King (W)
- Aerial radiological monitoring surveys, Northeastern United States
  - P. Popenoe (W)

Alabama:
- Clinton iron ores of the southern Appalachians
  - R. P. Sheldon (D)
- Coal resources
  - W. C. Culbertson (D)
- *Warrior quadrangle, (coal)
  - W. C. Culbertson (D)
- Pre-Selma Cretaceous rocks of Alabama and adjacent States
  - L. C. Conant (Tripoli, Libya)
- Mesozoic rocks of Florida and eastern Gulf coast
  - P. L. Applin (Jackson, Miss.)

Alaska:

General geology:
- Index of literature on Alaskan geology
  - E. H. Cobb (M)
- Tectonic map
  - G. Gryc (W)
- Physiographic divisions
  - C. Wahrhaftig (M)
- Glacial map
  - T. N. V. Karlstrom (W)
- Surficial deposits
  - T. N. V. Karlstrom (W)
- Compilation of geologic maps, 1:250,000 quadrangles
  - W. H. Condon (M)
- Cenozoic geology of western Alaska
  - D. M. Hopkins (M)
- *Petrology and volcanism, Katmai National Monument
  - G. H. Curtis (M)
- Windy-Curry area
  - R. Kachadoorian (M)
- *Mount Michelson area
  - E. G. Sable (Ann Arbor, Mich.)
- **Eastern Chugach Mountains traverse
  - D. J. Miller (M)
- **Lower Yukon-Norton Sound region
  - J. M. Hoare (M)
- *Eastern Aleutian Islands
  - G. D. Fraser (D)
- *Western Aleutian Islands
  - G. D. Fraser (D)

Mineral resources:
- Metallogenic provinces
  - C. L. Sainsbury (M)
- Geochemical prospecting techniques
  - R. M. Chapman (D)

Alaska—Continued

Mineral resources—Continued
- **Klukwan iron district
  - E. C. Robertson (W)
- **Southern Brooks Range (copper, precious metals)
  - W. P. Brosgé (M)
- **Regional geology and mineral resources, southeastern Alaska
  - E. H. Lathram (M)
- Quicksilver deposits, southwestern Alaska
  - E. M. MacKevett, Jr. (M)
- *Nome C–1 and D–1 quadrangles (gold)
  - C. L. Hummel (M)
- *Tofty placer district (gold, tin)
  - D. M. Hopkins (M)
- Seward Peninsula tin investigations
  - P. L. Killeen (W)
- **Lower Kuskokwim-Bristol Bay region (mercury, antimony, zinc)
  - J. M. Hoare (M)
- *Heceta-Tuxekan area (high-calcium limestone)
  - G. D. Eberlein (M)
- Uranium-thorium reconnaissance
  - E. M. MacKevett, Jr. (M)
- Map of coal fields
  - F. F. Barnes (M)
- *Matanuska coal field
  - F. F. Barnes (M)
- Tertiary history of the Yukon-Tanana Upland (coal)
  - D. M. Hopkins (M)
- *Nenana coal investigations
  - C. Wahrhaftig (M)
- Matanuska stratigraphic studies (coal)
  - A. Grantz (M)
- **Stratigraphic and structural studies of the Lower Yukon-Koyukuk area (petroleum)
  - W. W. Patton, Jr. (M)
- **Nelchina area (petroleum)
  - A. Grantz (M)
- *Iniskin-Tuxedni region (petroleum)
  - R. L. Detterman (M)
- **Buckland and Huslia Rivers area, west-central Alaska
  - W. W. Patton, Jr. (M)
- **Gulf of Alaska province (petroleum)
  - D. J. Miller (M)
- **Northern Alaska petroleum investigations
  - G. Gryc (W)

Engineering geology and permafrost:
- *Nuclear test site evaluation, Chariot
  - G. D. Eberlein (M)
- *Nuclear test site evaluation, Katalla
  - G. D. Eberlein (M)
- Arctic ice and permafrost studies
  - A. H. Lachenbruch (M)
- Origin and stratigraphy of ground ice in central Alaska
  - T. L. Péwé (College, Alaska)
- Ground ice and permafrost, Point Barrow
  - R. F. Black (Madison, Wis.)
- *Lituya Bay giant-wave investigation
  - D. J. Miller (M)
- *Anchorage and vicinity (construction-site planning)
  - R. D. Miller (D)

Alaska—Continued
Engineering geology and permafrost—Continued
*Mt. Hayes D-3 and D-4 quadrangles (construction-site planning)
T. L. Péwé (College, Alaska)
*Engineering geology of Talkeetna-McGrath highway
T. L. Péwé (College, Alaska)
*Surficial and engineering geology studies and construction materials sources
T. L. Péwé (College, Alaska)
Galena area (construction-site planning)
T. L. Péwé (College, Alaska)
*Surficial geology of the southwestern Copper River basin (construction-site planning)
J. R. Williams (W)
*Surficial geology of the southeastern Copper River basin, (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the northeastern Copper River basin (construction-site planning)
O. J. Ferrians, Jr. (Glennallen, Alaska)
*Surficial geology and permafrost of the Johnson River district
G. W. Holmes (W)
**Surficial geology of the Upper Kuskokwim region (construction-site planning)
A. T. Fernald (W)
**Surficial geology of the Kobuk River valley (construction-site planning)
A. T. Fernald (W)
**Surficial geology of the Kenai lowland (construction-site planning)
T. N. V. Karlstrom (W)
*Surficial geology of the Big Delta area (construction-site planning)
G. W. Holmes (W)
*Surficial geology of the Barter Island-Mt. Chamberlin area (construction-site planning)
G. W. Holmes (W)
**Surficial geology of the Yukon Flats district (construction-site planning)
J. R. Williams (W)
*Surficial geology of the Valdez-Tiekel belt (construction-site planning)
H. W. Coulter (W)
*Surficial geology of the Upper Tanana River valley (construction-site planning)
A. T. Fernald (W)
*Surficial geology of the Susitna-Maclaren River area (construction-site planning)
D. R. Nichols (W)
*Surficial geology of the Slana-Tok area (construction-site planning)
H. R. Schmoll (W)
*Surficial geology of the Seward-Portage Railroad belt (construction-site planning)
T. N. V. Karlstrom (W)
Surficial geology of the Arctic Slope region
H. W. Coulter (W)
Paleontology:
Upper Paleozoic stratigraphic paleontology, Western United States and Alaska
J. T. Dutro, Jr. (W)

Alaska—Continued
Paleontology—Continued
Cretaceous Foraminifera of the Nelchina area
H. R. Bergquist (W)
Cenozoic mollusks
F. S. MacNeil (M)
Geophysical studies:
Geophysical studies, ground surveys
D. F. Barnes (M)
Geophysical studies, airborne surveys
G. E. Andreasen (W)
Yukon Flats-Kandik aeromagnetic survey
G. E. Andreasen (W)
Koyukuk aeromagnetic studies
G. E. Andreasen (W)
Copper River basin geophysical studies
G. E. Andreasen (W)
Cook Inlet aeromagnetic survey
G. E. Andreasen (W)
Aerial radiological monitoring surveys, Chariot site
R. G. Bates (W)
Arizona:
General geology:
Arizona state geologic map
J. R. Cooper (D)
Devonian rocks and paleogeography of central Arizona
C. Teichert (D)
Diatremes, Navajo and Hopi Indian Reservations
E. M. Shoemaker (M)
Permian stratigraphy, northeastern Arizona
C. B. Read (Albuquerque, N.M.)
History of Supai-Hermit formations
E. D. McKee (D)
Stratigraphy of the Redwall limestone
E. D. McKee (D)
*Holy Joe Peak quadrangle
M. H. Krieger (M)
*Eastern Mogollon Rim area
E. J. McKay (D)
**Paleozoic and Cenozoic rocks in the Alpine-Nutrioso area, Apache County
C. T. Wrucke (D)
*Elgin quadrangle
R. B. Raup (M)
*Upper Gila River basin, Arizona, New Mexico
R. B. Morrison (D)
*Geology of southern Cochise County
P. T. Hayes (D)
Mineral resources:
Geochemical halos of mineral deposits, Basin and Range province
L. C. Huff (D)
*Christmas quadrangle (copper, iron)
C. R. Willden (M)
*Geology and copper deposits of the Twin Buttes areas (copper)
J. R. Cooper (D)
*Prescott-Paulden area (copper)
M. H. Krieger (M)
*Mammoth quadrangle (copper)
S. C. Creasey (M)
Contact-metamorphic deposits of the Little Dragoons area (copper)
J. R. Cooper (D)

Arizona—Continued
Mineral resources—Continued
*Klondyke quadrangle (copper)
F. S. Simons (D)
*Globe-Miami area (copper)
N. P. Peterson (Globe, Ariz.)
*Bradshaw Mountains (copper)
C. A. Anderson (W)
*MacFadden Peak quadrangle and adjacent areas (asbestos)
A. F. Shride (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)
Colorado Plateau botanical prospecting studies
F. J Kleinhampl (M)
Relation of fossil wood to uranium deposits, with emphasis on the Colorado Plateau
R. A. Scott (D)
Colorado Plateau ground-water studies (uranium)
D. Jobin (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
San Rafael group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
Carrizo Mountains area, Arizona-New Mexico (uranium)
J. D. Strobell (D)
East Vermillion Cliffs area (uranium, vanadium)
R. G. Peterson (Boston, Mass.)
Uranium deposits of the Dripping Spring quartzite of southeastern Arizona
H. C. Granger (D)
Studies of uranium deposits
R. B. Raup (D)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)
Engineering and geophysical studies:
Great Basin geophysical studies
D. R. Mabey (M)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Arkansas:
Magnet Cove niobium investigations
L. V. Blade (D)
Aeromagnetic studies in the Newport, Arkansas, and Ozark bauxite areas
A. Jespersen (W)

Arkansas—Continued
Barite deposits
D. A. Brobst (D)
*Northern Arkansas oil and gas investigations
E. E. Glick (D)
*Ft. Smith district, Arkansas and Oklahoma (coal and gas)
T. A Hendricks (D)
*Arkansas Basin coal investigations
B. R. Haley (D)
California:
General geology:
*Big Maria Mountains quadrangle
W. B. Hamilton (D)
*Funeral Peak quadrangle
H. D. Drewes (D)
Death Valley
C. B. Hunt (D)
*Ash Meadows quadrangle, California-Nevada
C. S. Denny (W)
*Mt. Pinchot quadrangle
J. G. Moore (M)
*Independence quadrangle
D. C. Ross (M)
*Blanco Mountain quadrangle
C. A. Nelson (Los Angeles, Calif.)
Glaciation in the San Joaquin Basin
F. M. Fryxell (Rock Island, Ill.)
*Salinas Valley
D. L. Durham (M)
*San Andreas fault
L. F. Noble (Valyermo, Calif.)
*Merced Peak quadrangle
D. L. Peck (M)
*Petrology of the Burney area
G. A. Macdonald (Honolulu, Hawaii)
*Investigation of the Coast Range ultramafic rocks
E. H. Bailey (M)
Glaucophane schist terrane within the Franciscan formation
R. G. Coleman (M)
*Weaverville, French Gulch, and Hayfork quadrangles, southern Klamath Mountains
W. P. Irwin (M)
Mineral resources:
Lateritic nickel deposits of the Klamath Mountains, Oregon-California
P. E. Hotz (M)
*Geologic study of the Sierra Nevada batholith (tungsten, gold, base metals)
P. C. Bateman (M)
*Bishop tungsten district
P. C. Bateman (M)
*Eastern Sierra tungsten area: Devil's Postpile, Mt. Morrison, and Casa Diablo quadrangles (tungsten, base metals)
C. D Rinehart (M)
Structural geology of the Sierra foothills mineral belt (copper, zinc, gold, chromite)
L. D. Clark (M)
*Panamint Butte quadrangle including special geochemical studies (lead-silver)
W. E. Hall (W)

California—Continued
Mineral resources—Continued
*Cerro Gordo quadrangle (lead, zinc)
W. C. Smith (M)
*Mt. Diablo area (quicksilver, copper, gold, silver)
E. H. Pampeyan (M)
*Geology and origin of the saline deposits of Searles Lake (boron)
G. I. Smith (M)
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
*Western Mojave Desert (boron)
T. W. Dibblee, Jr (M)
*Furnace Creek area (boron)
J. F. McAllister (M)
*Eastern Los Angeles basin (petroleum)
J. E. Schoellhamer (M)
Rocks and structures of the Los Angeles basin, and their gravitational effects (petroleum)
T. H. McCulloh (Riverside, Calif.)
*Southeastern Ventura basin (petroleum)
E. L. Winterer (Los Angeles, Calif.)
*Northwest Sacramento Valley (petroleum)
R. D. Brown, Jr. (M)
Engineering geology:
*Surficial geology of the Beverly Hills, Venice, and Topanga quadrangles, Los Angeles (urban geology)
J T. McGill (Los Angeles, Calif.)
*San Francisco Bay area, San Francisco South quadrangle (urban geology)
M. G. Bonilla (M)
*San Francisco Bay area, San Francisco North quadrangle (urban geology)
J. Schlocker (M)
*Oakland East guadrangle (urban geology)
D. H. Radbruch (M)
Geophysical studies:
Volcanism and crustal deformation
L. C. Pakister (D)
Great Basin geophysical studies
D. R. Mabey (M)
Geophysical study of major crustal units, Sierra Nevada
H. W. Oliver (W)
Geophysical studies of relation of ore deposits to batholithic intrusions, Sierra Nevada area
H. W. Oliver (W)
Aerial radiological monitoring surveys, San Francisco
J. A. Pitkin (W)
Aerial radiological monitoring surveys, Los Angeles
R. B. Guillou (W)
Paleontology:
Cenozoic Foraminifera, Colorado Desert
P. J. Smith (M)
*Geology and paleontology of San Nicolas Island
J. G. Vedder (M)
Geology and paleontology of the Cuyama Valley area
J. G. Vedder (M)
Foraminifera of the Lodo formation, central California
M. C. Israelsky (M)
Colorado:
General geology:
Age determinations: rocks in Colorado
H. Faul (W)

Colorado—Continued
General geology—Continued
Significance of lead-alpha age variation in batholiths of the Colorado Front Range
E. S. Larsen, 3d (W)
Petrology and geochemistry of the Laramide intrusives in the Colorado Front Range
E. S. Larsen, 3d (W)
Petrology and geochemistry of the Boulder Creek batholith, Colorado Front Range
E. S. Larsen, 3d (W)
*Metamorphism and structure of Precambrian quartzite and associated rocks, Coal Creek area
J. D. Wells (D)
*Upper South Platte River, North Fork
G. R. Scott (D)
*Mountain Front recharge area
G. R. Scott (D)
*Glenwood Springs quadrangle
N. W. Bass (D)
Devonian stratigraphy of the middle Rocky Mountain area, Colorado and adjacent States
V. E. Swanson (D)
Pennsylvanian and Permian stratigraphy, Rocky Mountain Front Range, Colorado and Wyoming
E. K. Maughan (D)
Investigation of Jurassic stratigraphy, south-central Wyoming and northwestern Colorado
G. N. Pipiringos (D)
Upper Cretaceous stratigraphy, northwestern Colorado and northeastern Utah
A. D. Zapp (D)
Paleontology and stratigraphy of the Pierre shale, Front Range
W. A. Cobban (D)
Mineral resources:
Ore deposition at Creede
E. W. Roedder (W)
*Creede and Summitville districts (base and precious metals, and fluorspar)
T. A. Steven (D)
*Tenmile Range, including the Kokomo mining district (base and precious metals)
A. H. Koschmann (D)
*Central City-Georgetown area, including studies of the Precambrian history of the Front Range (base, precious, and radioactive metals)
P. K. Sims (D)
*San Juan mining area, including detailed study of the Silverton Caldera (lead, zinc, silver, gold, copper)
R. G. Luedke (W)
*Holy Cross quadrangle and the Colorado mineral belt (lead, zinc, silver, copper gold)
O. Tweto (D)
*Rico district (lead, zinc, silver)
E. T. McKnight (W)
*Minturn quadrangle (zinc, silver, copper, lead, gold)
T. S. Lovering (D)
*Lake George district (beryllium)
C. C. Hawley (D)
*Poncha Springs and Saguache quadrangles (fluorspar)
R. E. Van Alstine (W)
Clay studies, Colorado Plateau
L. G. Schultz (D)

Colorado—Continued
Mineral resources—Continued
Wallrock alteration and its relation to thorium deposition in the Wet Mountains
E. S. Larsen, 3d (W)
*Wet Mountains (thorium, base and precious metals)
M. R. Brock (W)
*Powderhorn area, Gunnison County (thorium)
J. C. Olson (D)
*Maybell-Lay area, Moffat County (uranium)
M. J. Bergin (W)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Uranium-vanadium deposits in standstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Relation of fossil wood to uranium deposits, with emphasis on the Colorado Plateau
R. A. Scott (D)
Colorado Plateau botanical prospecting studies.
F. J. Kleinhampl (M)
Colorado Plateau ground-water studies (uranium)
D. Jobin (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
San Rafael group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (D)
*Ralston Buttes (uranium)
D. M. Sheridan (D)
*Klondike Ridge area (uranium, copper, manganese, salines)
J. D. Vogel (D)
*Western San Juan Mountains (uranium, vanadium, gold)
C. S. Bromfield (D)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
*La Sal area, Utah-Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Lisbon Valley area, Utah-Colorado (uranium, vanadium, copper)
G. W. Weir (M)
Uravan district (vanadium, uranium)
R. L. Boardman (W)
*Slick Rock district (uranium, vanadium)
D. R. Shawe (D)
Exploration for uranium deposits in the Gypsum Valley district
C. F. Withington (W)
*Bull Canyon district (vanadium, uranium)
D. Elston (D)
*Ute Mountains (uranium, vanadium)
E. B. Ekren (D)

Colorado—Continued
Mineral resources—Continued
Subsurface geology of the Dakota sandstone, Colorado and Nebraska (oil and gas)
N. W. Bass (D)
*Animas River area, Colorado and New Mexico (coal, oil, and gas)
H. Barnes (D)
*North Park (coal, oil, and gas)
D. M. Kinney (W)
*Western North Park (coal, oil, and gas)
W. J. Hail (D)
*Trinidad coal field
R. B. Johnson (D)
*Carbondale coal field
J. R. Donnell (D)
**Oil shale investigations
D. C. Duncan (W)
Oil shale resources, northwestern Colorado
J. R. Donnell (D)
*Grand-Battlement Mesa oil shale
J. R. Donnell (D)
Engineering geology and geophysical studies:
*Upper Green River valley (construction-site planning)
W. R. Hansen (D)
*Denver and vicinity; Golden and Morrison quadrangles (urban geology)
R. Van Horn (D)
Black Canyon of the Gunnison River (construction-site planning)
W. R. Hansen (D)
*Air Force Academy (construction-site planning)
D. J. Varnes (D)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Salt anticlines, Paradox Basin, Colorado and Utah (test-site evaluation)
D. P. Elston (D)
Salt anticline studies, Colorado and Utah (test-site evaluation)
E. M. Shoemaker (M)
Connecticut:
*Ansonia, Mount Carmel, and Southington quadrangles; bedrock geologic mapping
C. E. Fritts (D)
*Ashaway quadrangle, Rhode Island-Connecticut; bedrock geologic mapping
G. T. Feininger (Boston, Mass.)
*Avon and New Hartford quadrangles; bedrock and surficial-geologic mapping
R. W. Schnabel (D)
*Bristol and New Britain quadrangles; bedrock and surficial geologic mapping
H. E. Simpson (D)
*Broadbrook, Manchester, and Windsor Locks quadrangles; surficial geologic mapping
R. B. Colton (D)
*Carolina, Quonochontaug, Narragansett Pier, and Wickford quadrangles, R.I. and Ashaway and Watch Hill quadrangles, Connecticut-Rhode Island, surficial geologic mapping
J. P. Schafer (Boston, Mass.)

Connecticut—Continued

*Columbia, Fitchville, Norwich, Marlboro, and Willimantic quadrangles; bedrock geologic mapping
G. L. Snyder (D)

*Coventry Center and Kingston quadrangles, Rhode Island and Watch Hill quadrangle, Connecticut-Rhode Island; bedrock geologic mapping
G. E. Moore, Jr. (Columbus, Ohio)

*Durham quadrangle; surficial geologic mapping
H. E. Simpson (D)

*Fitchville and Norwich quadrangles; surficial geologic mapping
P. M. Hanshaw (D)

*Hampton, Plainfield, and Scotland quadrangles; bedrock geologic mapping
H. R. Dixon (D)

*Meriden quadrangle; bedrock and surficial geologic mapping
P. M. Hanshaw (D)

*Montville, New London, Niantic, and Uncasville quadrangles; bedrock and surficial geologic mapping
R. Goldsmith (D)

*Mystic and Old Mystic quadrangles; bedrock geologic mapping
R. Goldsmith (D)

*Springfield South quadrangle, Massachusetts and Connecticut; bedrock and surficial geologic mapping
J. H. Hartshorn (Boston, Mass.)

*Tarrifville and Windsor Lake quadrangles; bedrock geologic mapping
R. W. Schnabel (D)

Delaware:

Correlation of aeromagnetic studies and areal geology, Fall Zone
R. W. Bromery (W)

Florida:

Phosphate deposits of northern Florida
G. H. Espenshade (W)

*Land-pebble phosphate deposits
J. B. Cathcart (D)

Mesozoic rocks of Florida and eastern Gulf Coast
P. L. Applin (Jackson, Miss.)

Georgia:

Pre-Selma Cretaceous rocks of Alabama and adjacent States
L. C. Conant (Tripoli, Libya)

Mesozoic rocks of Florida and eastern Gulf Coast
P. L. Applin (Jackson, Miss.)

Clinton iron ores of the southern Appalachians
R. P. Sheldon (D)

Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)

Aerial radiological monitoring surveys, Georgia Nuclear Aircraft Laboratory
J. A. MacKallor (W)

Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)

Hawaii:

Distribution and origin of the Kauai bauxite deposits
S. H. Patterson (Lihue, Kauai, Hawaii)

Hawaii—Continued

Geological, geochemical and geophysical studies of Hawaiian volcanology
K. J. Murata (Hawaii)

Pahala Ash studies
K. J. Murata (Hawaii)

Idaho:

General geology:

**South Central Idaho
C. P. Ross (D)

*Cross-section of the Idaho batholith; Yellow Pine quadrangle
B. F. Leonard (D)

*Owyhee and Mt. City quadrangles, Nevada-Idaho
R. R. Coats (M)

Petrology of volcanic rocks, Snake River valley,
H. A. Powers (D)

*Snake River valley, western region
H. A. Powers (D)

*Snake River valley, American Falls region
H. A. Powers (D)

**Regional geology and structure, Snake River valley
H. A. Powers (D)

**Mackay quadrangle
C. P. Ross (D)

*Leadore, Gilmore, and Patterson quadrangles
E. T. Ruppel (D)

*Metamorphism of the Orofino area
A. Hietanen-Makela (M)

*Leesburg quadrangle
W. H. Nelson (D)

*Sedimentary petrology and geochemistry of the Belt series; Elmira, Mt. Pend Oreille, Packsaddle Mountains, and Clark Fork quadrangles, Idaho-Montana
J. E. Harrison (D)

Mineral resources:

*General geology of the Coeur d'Alene mining district (lead, zinc, silver)
A. B. Griggs (M)

Ore deposits of the Coeur d'Alene mining district (lead, zinc, silver)
V. C. Fryklund, Jr. (Spokane, Wash.)

*Thunder Mountain niobium area, Montana-Idaho
R. L. Parker (D)

*Blackbird Mountain area (cobalt)
J. S. Vhay (Spokane, Wash.)

*Greenacres quadrangle, Wash.-Idaho (high-alumina clays)
P. L. Weis (Spokane, Wash.)

Geochemistry and petrology of western phosphate deposits
R. A. Gulbrandsen (M)

Stratigraphy and resources of the Phosphoria formation (phosphate, minor elements)
V. E. McKelvey (M)

*Soda Springs quadrangle, including studies of the Bannock thrust zone (phosphate)
F. C. Armstrong (Spokane, Wash.)

*Morrison Lake quadrangle, Idaho-Montana (phosphate)
E. R. Cressman (M)

**Irwin quadrangle, Caribou Mountains (phosphate, oil and gas)
L. S. Gardner (Bangkok, Thailand)

*Aspen Range-Dry Ridge area (phosphate)
T. M. Cheney (M)

Idaho—Continued
Mineral resources—Continued
*Radioactive placer deposits of central Idaho
D. L. Schmidt (Seattle, Wash.)
Geophysical studies:
Pacific Northwest geophysical studies
D. J. Stuart (M)
Volcanism and crustal deformation geophysical studies
L. C. Pakiser (D)
Correlation of aeromagnetic studies and areal geology, Pend Oreille area
E. R. King (W)
Aerial radiological monitoring surveys, National Reactor Testing Station
R. G. Bates (W)
Illinois:
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
*Wisconsin zinc-lead mining district
T. E. Mullens (D)
Aerial radiological monitoring surveys, Chicago
R B. Guillou (W)
*Geologic development of the Ohio River valley
L. L. Ray (W)
Lower Pennsylvanian floras of Illinois and adjacent States
C. B. Read (Albuquerque, N. Mex.)
Indiana:
*Geology and coal deposits, Terra Haute and Dennison quadrangles
P. Averitt (D)
Aerial radiological monitoring surveys, Chicago
R. B. Guillou (W)
Lower Pennsylvanian floras of Illinois and adjacent States
C. B. Read (Albuquerque, N. Mex)
*Quaternary geology of the Owensboro quadrangle, Kentucky-Indiana
L. L. Ray (W)
*Geologic development of the Ohio River valley
L. L Ray (W)
Iowa:
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
*Wisconsin zinc-lead mining district
T. E. Mullens (D)
*Omaha-Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
Lower Pennsylvanian floras of Illinois and adjacent States
C. B. Read (Albuquerque, N. Mex.)
Kansas:
*Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)
*Wilson County (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
Paleozoic stratigraphy of the Sedgwick Basin (oil and gas)
W. L. Adkison (Lawrence, Kans.)
*Shawnee County (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)

Kentucky:
*Geology of the southern Appalachian folded belt, Kentucky, Tennessee, and Virginia
L. D. Harris (W)
Fluorspar deposits of northwestern Kentucky
R. D. Trace (W)
*Salem quadrangle (fluorspar)
R. D. Trace (W)
Clay deposits of the Olive Hill bed of eastern Kentucky
J. W. Hosterman (W)
*Quaternary geology of the Owensboro quadrangle, Kentucky-Indiana
L. L. Ray (W)
*Petroleum geology of Duffield, Stickleyville, Keokee, Olinger, and Pennington Gap quadrangles, Virginia and Kentucky
L. D. Harris (W)
*Eastern Kentucky coal investigations
J. W. Huddle (W)
Aeromagnetic studies, Middlesboro-Morristown area, Tennessee-Kentucky-Virginia
R. W. Johnson, Jr. (Knoxville, Tenn.)
Aerial radiological monitoring surveys, Oak Ridge National Laboratory
R. G. Bates (W)
*Geologic development of the Ohio River valley
L. L. Ray (W)
Stratigraphy of cavern fills, Mammoth Cave
W. E. Davies (W)
Vertebrate paleontology, Big Bone Lick
F. C. Whitmore, Jr. (W)
Maine:
Age determinations: granites of Maine
H. Faul (W)
*Greenville quadrangle
G. H. Espenshade (W)
*Bedrock geology of the Danforth, Forest, and Vanceboro quadrangles
D. M. Larrabee (W)
*Attean quadrangle
A. L. Albee (Pasadena, Calif.)
*Hydrogeochemical prospecting in the Forks quadrangle
F. C. Canney (D)
*Bridgewater quadrangle (manganese)
L. Pavlides (W)
*Electromagnetic and geologic mapping in Island Falls quadrangle
E. B. Ekren (D)
*Aeromagnetic and areal geology studies of the Stratton quadrangle
A. Griscom (W)
Aeromagnetic surveys
J. W. Allingham (W)
Gravity studies
M. F. Kane (W)
Maryland:
*Potomac Basin studies, Maryland, Virginia, and West Virginia
J. T. Hack (W)
Clay deposits
M. M. Knechtel (W)
*Allegany County (coal)
W. de Witt, Jr. (W)

Maryland—Continued
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
R. B. Guillou (W)
Airborne radioactivity and environmental studies, Washington County
R. M. Moxham (W)
*Correlation of aeromagnetic studies and areal geology, Montgomery County
A. Griscom (W)
Massachusetts:
*Assawompsett Pond quadrangle; surficial geologic mapping
C. Koteff (Boston, Mass.)
*Athol quadrangle; bedrock and surficial geologic mapping
D. F. Eschman (Ann Arbor, Mich.)
*Ayer quadrangle; bedrock geologic mapping
R. H. Jahns (University Park, Pa.)
*Billerica, Lowell, Tyngsboro, and Westford quadrangles; bedrock and surficial geologic mapping
R. H. Jahns (University Park, Pa.)
*Bridgewater and Taunton quadrangles; surficial geologic mapping
J. H. Hartshorn (Boston, Mass.)
*Clinton and Shrewsbury quadrangles; bedrock geologic mapping
R. F. Novotny (Boston, Mass.)
*Concord and Georgetown quadrangles; bedrock and surficial geologic mapping
N. P. Cuppels (Boston, Mass.)
*Duxbury and Scituate quadrangles and Fresh Pond-Mystic Lake area; surficial geologic mapping
N. E. Chute (Syracuse, N. Y.)
*Greenfield quadrangle, surficial geologic mapping
R. H. Jahns (University Park, Pa.)
*Lawrence, Reading, South Groveland, and Wilmington quadrangles; bedrock geologic mapping
R. O. Castle (Los Angeles, Calif.)
*North Adams quadrangle; bedrock geologic mapping
N. Herz (Belo Horizonte, Brazil)
*Norwood quadrangle; bedrock and surficial geologic mapping.
N. E. Chute (Syracuse, N. Y.)
*Reading and Salem quadrangles; surficial geologic mapping.
R. N. Oldale (Boston, Mass.)
*Salem quadrangle; bedrock geologic mapping
P. Toulmin, III (W)
*Springfield South quadrangle, Massachusetts and Connecticut; bedrock and surficial geologic mapping
J. H. Hartshorn (Boston, Mass.)
*Dennis and Harwich quadrangles; surficial geologic mapping and special seismic studies of engineering problems
L. W. Currier (W)
Research and application of geology and seismology to Public Works planning
L. W. Currier (W)
Sea-cliff erosion studies
C. A. Kaye (Boston, Mass.)
Vertebrate faunas, Martha's Vineyard
F. C. Whitmore, Jr. (W)
Michigan:
*Iron River-Crystal Falls district (iron)
H. L. James (M)

Michigan—Continued
*East Marquette district (iron)
J. E. Gair (D)
*Southern Dickinson County (iron)
R. W. Bayley (M)
*Eastern Iron County (iron)
K. L. Wier (Iron Mountain, Mich.)
*Michigan copper district
W. S. White (W)
Geophysical studies in the Lake Superior region
G. D. Bath (M)
*Lake Algonquin drainage
J. T. Hack (W)
Minnesota:
*Cuyuna North Range (iron)
R. G. Schmidt (W)
Geophysical studies in the Lake Superior region
G. D. Bath (M)
Mississippi:
Pre-Selma Cretaceous rocks of Alabama and adjacent States
L. C. Conant (Tripoli, Libya)
Oligocene gastropods and pelecypods
F. S. MacNeil (M)
Missouri:
*Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
Aeromagnetic studies in the Newport, Arkansas, and Ozark bauxite areas
A. Jesperson (W)
Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phospate)
W. Danilchik (Quetta, Pakistan)
Correlation of aeromagnetic studies and areal geology, southeast Missouri
J. W. Allingham (W)
Montana:
General geology:
Stratigraphy of the Belt series
C. P. Ross (D)
Mesozoic stratigraphic paleontology
W. A. Cobban (D)
Northern Great Plains Pleistocene reconnaissance, Montana and North Dakota
R. B. Colton (D)
Carbonatite deposits
W. T. Pecora (W)
*Petrology of the Bearpaw Mountains
W. T. Pecora (W)
*Petrology of the Wolf Creek area
R. G. Schmidt (W)
*Sedimentary petrology and geochemistry of the Belt series; Elmira, Mt. Pend Oreille, Packsaddle Mountains, and Clark Fork quadrangles, Idaho-Montana
J. E. Harrison (D)
Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming and Nebraska
H. A. Tourtelot (D)
*Alice Dome—Sumatra area
H. R. Smith (D)
*Quaternary geology of the Browning area and the east slope of Glacier National Park
G. M. Richmond (D)

Montana—Continued
General geology—Continued
*Bedrock and surficial geology, Big Sandy Creek area
R. M. Lindvall (D)
*Geology of the Livingston-Trail Creek area (coal)
A. E. Roberts (D)
*Maudlow quadrangle
B. Skipp (D)
*Duck Creek Pass quadrangle
W. H. Nelson (D)
*South Gallatin Range
I. J. Witkind (D)
*Gravelly Range-Madison Range
J. B. Hadley (D)
*Three Forks quadrangle
G. D. Robinson (D)
*Toston quadrangle
G. D. Robinson (D)
*Holter Lake quadrangle
G. D. Robinson (D)
*Willis quadrangle
W. B. Myers (D)
Mineral resources:
Manganese deposits of the Philipsburg area (manganese and base metals)
W. C. Prinz (Spokane, Wash.)
Chromite resources and petrography of the Stillwater ultramafic complex
E. D. Jackson (M)
*Thunder Mountain niobium area, Montana-Idaho
R. L. Parker (D)
*General geology of the Coeur d'Alene mining district (lead, zinc, silver)
A. B. Griggs (M)
Ore deposits of the Coeur d'Alene mining district (lead, zinc, silver)
V. C. Fryklund, Jr. (Spokane, Wash.)
*Boulder batholith area (base, precious, and radioactive metals)
M. R. Klepper (W)
*Morrison Lake quadrangle, Idaho-Montana (phosphate)
E. R. Cressman (M)
Stratigraphy and resources of Permian rocks in western Montana (phosphate, minor elements)
R. W. Swanson (Spokane, Wash.)
Stratigraphy and resources of Permian rocks in southwestern Montana (phosphate, minor elements)
E. R. Cressman (M)
*Geology of the Winnett-Mosby area (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota and South Dakota
C. A. Sandberg (D)
Reconnaissance geology of the Burney-Broadus coalfield, Wyoming and Montana
W. W. Olive (W)
Geology of uranium in lignites, Montana, North Dakota, and South Dakota
N. M. Denson (D)
Engineering geology:
Earthquake investigations, Hebgen Lake
J. B. Hadley (D)
*Sun River Canyon area
M. R. Mudge (D)

Montana—Continued
Engineering geology—Continued
*Wolf Point area (construction-site planning)
R. B. Colton (D)
*Great Falls area (urban geology and construction-site planning)
R. W. Lemke (D)
*Fort Peck area (construction-site planning)
H. D. Varnes (D)
Geophysical studies:
Pacific Northwest geophysical studies
D. J. Stuart (M)
Aeromagnetic studies, Three Forks area
I. Zietz (W)
Correlation of aeromagnetic studies and areal geology, Pend Oreille area
E. R. King (W)
Correlation of aeromagnetic studies and areal geology, Bearpaw Mountains
K. G. Books (W)
Magnetic studies of Montana laccoliths
R. G. Henderson (W)
Nebraska:
Devonian stratigraphy of the middle Rocky Mountain area, Colorado and adjacent States
V. E. Swanson (D)
Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
*Lower South Platte River
R. D. Miller (D)
*Lower Republican River
R. D. Miller (D)
Subsurface geology of Dakota sandstone, Colorado and Nebraska (oil and gas)
N. W. Bass (D)
Oil and gas investigations, central Nebraska basin
G. E. Prichard (D)
Omaha-Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
Nevada:
General geology:
*Schell Creek Range
H. D. Drewes (D)
*Owyhee and Mt. City quadrangles, Nevada-Idaho
R. R. Coats (M)
*Jarbidge area
R. R. Coats (M)
*Geology and paleontology of Kobeh Valley
T. B. Nolan (W)
*Railroad District, and the Dixie Flats, Pine Valley, and Robinson Mountain quadrangles
J. F Smith, Jr. (D)
*Horse Creek Valley quadrangle
H. Masursky (D)
*Mt. Lewis and Crescent Valley quadrangles
J. Gilluly (D)
*Frenchie Creek quadrangle
L. J. P. Muffler (D)
Cortez quadrangle
H. Masursky (D)

Nevada—Continued
General geology—Continued
*Fallon area
R. B. Morrison (D)
*Ash Meadows quadrangle, California-Nevada
C. S. Denny (W)
**Humboldt County
C. R. Willden (M)
**Mineral County
D. C Ross (M)
**Lincoln County
C. M. Tschanz (M)
*Las Vegas-Lake Mead area
C. R. Longwell (M)
Mineral resources:
Geochemical halos of mineral deposits, Basin and Range province
L. C. Huff (D)
Iron ore deposits
R. G. Reeves (M)
*Unionville and Buffalo Mountain quadrangles, Humboldt Range (iron, tungsten, silver, quicksilver)
R. E. Wallace (M)
*Osgood Mountains quadrangle (tungsten, quicksilver)
P. E. Hotz (M)
*Wheeler Peak and Garrison quadrangles, Snake Range, Nevada-Utah (tungsten)
D. H Whitebread (M)
*Lyon, Douglas, and Ormsby Counties (copper)
J. G. Moore (M)
*Regional geologic setting of the Ely district (copper, lead, zinc)
A. L. Brokaw (D)
Ione quadrangle (lead, quicksilver, tungsten)
C. J. Vitaliano (Bloomington, Ind.)
*Eureka area (zinc, lead, silver, gold)
T. B. Nolan (W)
**Eureka County (base and precious metals)
R. J. Roberts (M)
*Antler Peak quadrangle (base and precious metals)
R. J. Roberts (M)
*Geology and ore deposits of Bullfrog and Bear Mountain quadrangles (fluorite, bentonite, gold, silver)
H. R. Cornwall (M)
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
Geochemistry and petrology of western phosphate deposits
R. A. Gulbrandsen (M)
Stratigraphy and resources of the Phosphoria and Park City formations in Utah and Nevada (phosphate, minor elements)
T. M. Cheney (M)
Engineering geology and geophysical studies:
*Engineering geology of the Nevada Test Site area
V. R. Wilmarth (D)
Geophysical studies at the Nevada Test Site
W. H. Diment (D)
Great Basin geophysical studies
D. R. Mabey (M)
Aerial radiological monitoring surveys, Nevada Test Site
J. L. Meuschke (W)

New Hampshire:
Correlation of aeromagnetic studies and areal geology
R. W. Bromery (W)
New Jersey:
*Lower Delaware River basin, New Jersey-Pennsylvania
J. P. Owens (W)
*Middle Delaware River basin, New Jersey-Pennsylvania
A. A. Drake, Jr. (W)
*Selected iron deposits of the Northeastern States
A. F. Buddington (Princeton, N.J.)
Selected studies of uranium and rare-earth deposits in Pennsylvania and New Jersey
H. Klemic (W)
Correlation of aeromagnetic studies and areal geology, New York-New Jersey Highlands (iron)
A. Jesperson (W)
Correlation of aeromagnetic studies and areal geology, Delaware Fall Zone
R. W. Bromery (W)
New Mexico:
General geology:
New Mexico geologic map
C. H. Dane (W)
Southeastern New Mexico stratigraphic investigations
P. T. Hayes (D)
Stratigraphic significance of the genus *Tempskya* in southwestern New Mexico
C. B. Read (Albuquerque, N. Mex.)
Diatremes, Navajo and Hopi Indian Reservations
E. M. Shoemaker (M)
*Petrology of the Valles Mountains
R. L. Smith (W)
*Upper Gila River basins, Arizona-New Mexico
R. B. Morrison (D)
*Southern Oscura, northern San Andres Mountains
G. O. Bachman (D)
*Southern Peloncillo Mountains and Cedar Mountain area
C. T. Wrucke (D)
*Philmont Ranch quadrangle
G. D. Robinson (D)
Mineral resources:
Geochemical halos of mineral deposits, Basin and Range province
L. C. Huff (D)
*Central district (copper, zinc)
W. R. Jones (D)
Clay studies, Colorado Plateau
L. G. Schultz (D)
Potash and other saline deposits of the Carlsbad area
C. L. Jones (M)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)
Relative concentrations of chemical elements in different rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)

New Mexico—Continued
Mineral resources—Continued
Colorado Plateau ground-water studies
D. Jobin (D)
Relation of fossil wood to uranium deposits, with emphasis on the Colorado Plateau
R. A. Scott (D)
Colorado Plateau botanical exploration studies
F. J. Kleinhampl (M)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
San Rafael group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
Mineralogy of uranium-bearing rocks in the Grants area
A. D. Weeks (W)
Regional relationship of the uranium deposits of northwestern New Mexico
L. S. Hilpert (Salt Lake City, Utah)
*Laguna district (uranium)
R. H. Moench (D)
*Grants area (uranium)
R. E. Thaden (D)
Ambrosia Lake district (uranium)
H. C. Granger (D)
*Carrizo Mountains area, Arizona-New Mexico (uranium)
J. D. Strobell (D)
*Tucumcari-Sabinoso area (uranium)
R. L. Griggs (D)
Oil and gas fields
D. C. Duncan (W)
*Stratigraphy, northern Franklin Mountains, west Texas (petroleum)
R. L. Harbour (D)
*Animas River area, Colorado and New Mexico (coal, oil and gas)
H. Barnes (D)
*East side San Juan Basin (coal, oil, gas)
C. H. Dane (W)
*Raton Basin coking coal
A. A. Wanek (M)
Engineering geology and geophysical studies:
*Engineering geology of Gnome Test Site
V. R. Wilmarth (D)
*Nash Draw quadrangle (test-site evaluation)
J. D. Vine (M)
Seismic studies, southern Eddy County (test-site evaluation)
P. E. Byerly (D)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Aerial radiological monitoring surveys, Gnome site
R. B. Guillou (W)
Geophysical studies in the Rowe-Mora area
G. E. Andreasen (W)
New York:
*Glacial geology of the Elmira-Williamsport area, New York, Pennsylvania
C. S. Denny (W)
Cretaceous Foraminifera
N. F. Soh (W)

New York—Continued
*Richville quadrangle
H. M. Bannerman (W)
*Selected iron deposits of the Northeastern States
A. F. Buddington (Princeton, N. J.)
Metamorphism and origin of mineral deposits, Gouverneur area
A. E. J. Engel (Pasadena, Calif.)
Correlation of aeromagnetic studies and areal geology, New York-New Jersey Highlands (iron)
A. Jespersen (W)
Correlation of aeromagnetic studies and areal geology, Adirondacks area (iron)
J. R. Balsley (W)
*Gouverneur district (talc)
A. E. J. Engel (Pasadena, Calif.)
Stratigraphy of the Dunkirk and related beds
W. de Witt, Jr. (W)
*Stratigraphy of the Dunkirk and related beds in the Penn Yan and Keuka Lake quadrangles (oil and gas)
M. J. Bergin (W)
*Stratigraphy of the Dunkirk and related beds, in the Bath and Woodhull quadrangles (oil and gas)
J. F. Pepper (New Philadelphia, Ohio)
North Carolina:
*Great Smoky Mountains, Tennessee and North Carolina
J. B. Hadley (D)
*Grandfather Mountain
B. H. Bryant (D)
*Investigations of the Volcanic Slate series
A. A. Stromquist (W)
*Central Piedmont
H. Bell (W)
*Hamme tungsten deposit
J. M. Park, III (Raleigh, N.C.)
Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Swain County copper district
G. H. Espenshade (W)
Pegmatites of the Spruce Pine and Franklin-Sylva districts
F. G. Lesure (Knoxville, Tenn.)
*Geologic setting of the Spruce Pine pegmatite district (mica, feldspar)
D. A. Brobst (D)
*Shelby quadrangle (monazite)
W. C. Overstreet (W)
Central and western North Carolina regional aeromagnetic survey
R. W. Johnson, Jr. (Knoxville, Tenn.)
Airborne geophysical studies, Concord-Denton area
R. W. Johnson, Jr. (Knoxville, Tenn.)
North Dakota:
Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming, and Nebraska
H. A. Tourtelot (D)
Northern Great Plains Pleistocene reconnaissance, Montana and North Dakota
R. B. Colton (D)
Geology of uranium in lignites, Montana, North Dakota, and South Dakota
N. M. Denson (D)

North Dakota—Continued
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, and South Dakota
C. A. Sandberg (D)
Ohio:
*Geology and coal resources of Belmont County
H. L. Berryhill, Jr. (D)
Oklahoma:
*Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
Trace elements in rocks of Pennsylvanian age Oklahoma, Kansas, Missouri (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)
Anadarko Basin, Oklahoma and Texas, oil and gas studies
W. L. Adkison (Lawrence, Kans.)
*Ft. Smith district, Arkansas and Oklahoma (coal and gas)
T. A. Hendricks (D)
McAlester Basin (oil and gas)
S. E. Frezon (D)
Experimental aeromagnetic survey in northeast Oklahoma
I. Zietz (W)
Oregon:
Oregon state geologic map
G. W. Walker (M)
Foraminiferal studies of the Pacific Northwest
W. W. Rau (M)
Miocene mollusks
E. J. Trumbull (M)
Oligocene mollusks
E. J. Trumbull (M)
*Lower Umpqua River area
E. M. Baldwin (Eugene, Oreg.)
*Monument quadrangle
R. E. Wilcox (D)
*Gabbroic and associated intrusive rocks in the central part of the Oregon Coast Ranges
P. D. Snavely (M)
Lateritic nickel deposits of the Klamath Mountains, Oregon-California
P. E. Hotz (M)
*Ochoco Reservation, Lookout Mountain, Eagle Rock, and Post quadrangles (quicksilver)
A. C. Waters (Baltimore, Md.)
*Newport embayment (oil and gas)
P. D. Snavely, Jr. (M)
*Anlauf and Drain quadrangles (oil and gas)
L. Hoover (W)
*John Day area (chromite)
T. P. Thayer (W)
Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
W. C. Smith (M)
*Portland industrial area, Oregon and Washington (urban geology)
D. E. Trimble (D)
Pacific Northwest geophysical studies
D. J. Stuart (M)
Correlation between geologic and geophysical data, west-central Oregon
P. D. Snavely, Jr. (M)
Aerial radiological monitoring surveys, Hanford
R. G. Schmidt (W)
Geophysical studies, west-central Oregon
R. W. Bromery (W)

Pennsylvania:
*Glacial geology of the Elmira-Williamsport area, New York, Pennsylvania
C. S. Denny (W)
*Middle Delaware River basin, New Jersey-Pennsylvania
A. A. Drake, Jr. (W)
*Lower Delaware River basin, New Jersey-Pennsylvania
J. P. Owens (W)
*Investigations of the Lower Cambrian of the Philadelphia district
J. H. Wallace (W)
*Lehighton quadrangle (uranium)
H. Klemic (W)
Selected studies of uranium and rare-earth deposits in Pennsylvania and New Jersey
H. Klemic (W)
*Bituminous coal resources
E. D. Patterson (W)
*Western middle anthracite coal field
H. Arndt (W)
*Southern anthracite field
G. H. Wood, Jr. (W)
*Geology in the vicinity of anthracite mine drainage projects
T. M. Kehn (Mt. Carmel, Pa.)
Correlation of aeromagnetic studies and areal geology, Triassic
R. W. Bromery (W)
Correlation of aeromagnetic studies and areal geology, Fall Zone
R. W. Bromery (W)
Rhode Island:
*Wickford quadrangle; bedrock geologic mapping
R. B. Williams (Providence, R.I.)
*North Scituate quadrangle; surficial geologic mapping
C. S. Robinson (D)
*Kingston quadrangle; surficial geologic mapping
C. A. Kaye (Boston, Mass.)
*Hope Valley quadrangle; surficial geologic mapping
G. T. Feininger (Boston, Mass.)
*Chepachet, Crompton, and Tiverton quadrangles; bedrock geologic mapping
A. Quinn (Providence, R.I.)
*Coventry Center and Kingston quadrangles; and Watch Hill quadrangle, Connecticut-Rhode Island, bedrock geologic mapping
G. E. Moore, Jr. (Columbus, Ohio)
*Carolina, Quonochontaug, Narragansett Pier, and Wickford quadrangles, Rhode Island, and Ashaway and Watch Hill quadrangles, Connecticut-Rhode Island, surficial geologic mapping
J. P. Schafer (Boston, Mass.)
*Ashaway quadrangle, Rhode Island-Connecticut, bedrock geologic mapping
G. T. Feininger (Boston, Mass.)
South Carolina:
Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)
South Dakota:
Devonian stratigraphy of the middle Rocky Mountain area, Colorado and adjacent States
V. E. Swanson (D)

South Dakota—Continued
- Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming and Nebraska
  - H. A. Tourtelot (D)
- *Southern Black Hills (pegmatite minerals)
  - J. J. Norton (D)
- *Regional stratigraphic study of the Inyan Kara group, Black Hills (uranium)
  - W. J. Mapel (D)
- *Southern Black Hills (uranium)
  - G. B. Gott (D)
- *Harding County, South Dakota and adjacent areas (uraniferous lignite)
  - G. N. Pipiringos (D)
- Geology of uranium in lignites, Montana, North Dakota, and South Dakota
  - N. M. Denson (D)
- Geophysical studies in uranium geology
  - R. M. Hazlewood (D)
- Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, and South Dakota
  - C. A. Sandberg (D)
- Landslide studies in the Fort Randall Reservoir area
  - D. J. Varnes (D)

Tennessee:
- *Great Smoky Mountains, Tennessee and North Carolina
  - J. B. Hadley (D)
- *Geology of the southern Appalachian folded belt, Kentucky, Tennessee, and Virginia
  - L. D. Harris (W)
- Clinton iron ores of the southern Appalachians
  - R. P. Sheldon (D)
- Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
  - R. M. Hernon (D)
- Origin and depositional control of some Tennessee and Virginia zinc deposits
  - H. Wedow, Jr. (Knoxville, Tenn.)
- East Tennessee zinc studies
  - A. L. Brokaw (D)
- *Ivydell, Pioneer, Jellico West, and Ketchen quadrangles (coal)
  - K. J. Englund (W)
- *Knoxville and vicinity (urban geology)
  - J. M. Cattermole (D)
- Aeromagnetic studies, Middlesboro-Morristown area, Tennessee, Kentucky, and Virginia
  - R. W. Johnson, Jr. (Knoxville, Tenn.)
- Aerial radiological monitoring surveys, Oak Ridge National Laboratory
  - R. G. Bates (W)
- Central and western North Carolina regional aeromagnetic survey
  - R. W. Johnson, Jr. (Knoxville, Tenn.)

Texas:
- *Del Rio area
  - V. L. Freeman (D)
- *Sierra Blanca area
  - J. F. Smith, Jr. (D)
- *Sierra Diablo region
  - P. B. King (M)

Texas—Continued
- Mineralogy of uranium-bearing rocks in Karnes and Duval Counties
  - A. D. Weeks (W)
- Anadarko Basin, Oklahoma and Texas (oil and gas)
  - W. L. Adkison (Lawrence, Kans.)
- *Pennsylvanian oil and gas investigations
  - D. A. Myers (D)
- *Stratigraphy, northern Franklin Mountains, west Texas (petroleum)
  - R. L. Harbour (D)
- *Texas coastal plain geophysical and geological studies
  - D. H. Eargle (Austin, Tex.)
- Aerial radiological monitoring surveys, Gnome site
  - R. B. Guillou (W)
- Aerial radiological monitoring surveys, Killeen
  - J. A. Pitkin (W)
- Radon and helium studies
  - A. B. Tanner (Salt Lake City, Utah)
- Aerial radiological monitoring surveys, Fort Worth
  - J. A. Pitkin (W)

Utah:
- General geology:
  - Southwestern Utah geologic map
    - P. Averitt (D)
  - Upper Cretaceous stratigraphy, northwestern Colorado and northeastern Utah
    - A. D. Zapp (D)
  - *South half, Utah Valley
    - H. J. Bissell (Provo, Utah)
  - *Strawberry Valley and Wasatch Mountains
    - A. A. Baker (W)
  - *Little Cottonwood area
    - G. M. Richmond (D)
  - *Confusion Range
    - R. K. Hose (M)
  - *Northern Bonneville Basin
    - J. S. Williams (Provo, Utah)
- Mineral resources:
  - Geochemical halos of mineral deposits, Basin and Range province
    - L. C. Huff (D)
  - *Wheeler Peak and Garrison quadrangles, Snake Range, Nevada-Utah (tungsten)
    - D. H. Whitebread (M)
  - *San Francisco Mountains (tungsten, copper)
    - D. M. Lemmon (M)
  - *Regional geologic setting of the Bingham Canyon district (copper)
    - R. J. Roberts (M)
  - *Alta quadrangle (lead, silver, phosphate rock)
    - M. D. Crittenden, Jr. (M)
  - *East Tintic lead-zinc district, including extensive geochemical studies
    - H. T. Morris (M)
  - *Marysvale district (alunite)
    - R. L. Parker (D)
  - *Thomas and Dugway Ranges (fluorspar, beryllium)
    - M. H. Staatz (D)
  - Clay studies, Colorado Plateau
    - L. G. Schultz (D)
  - Geochemistry and petrology of western phosphate deposits
    - R. A. Gulbrandsen (M)

Utah—Continued
Mineral resources—Continued
Stratigraphy and resources of the Phosphoria and Park City formations in Utah and Nevada (phosphate, minor elements)
T. M. Cheney (M)
**Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
San Rafael group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
Colorado Plateau botanical exploration studies
F. J. Kleinhampl (M)
Relative concentrations of chemical elements in different rocks and ore deposits of the Colorada Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Colorado Plateau ground-water studies (uranium)
D. Jobin (D)
Relation of fossil wood to uranium deposits, with emphasis on the Colorado Plateau
R. A. Scott (D)
*La Sal area, Utah-Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Moab-Interriver area, east-central Utah (uranium)
E. N. Hinrichs (D)
Uranium ore controls of the San Rafael Swell
C. C. Hawley (D)
*Elk Ridge area (uranium)
R. Q. Lewis (D)
*Deer Flat area, White Canyon district (uranium, copper)
T. L. Finnell (D)
*White Canyon area (uranium, copper)
R. E. Thaden (D)
*Abajo Mountains (uranium, vanadium)
I. J. Witkind (D)
*Sage Plain area (uranium and vanadium)
L. C. Huff (D)
*Orange Cliffs area (uranium)
F. A. McKeown (D)
*Lisbon Valley area, Utah-Colorado (uranium, vanadium, copper)
G. W. Weir (M)
*Circle Cliffs area (uranium)
E. S. Davidson (Tucson, Ariz.)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)
*Cedar Mountain quadrangle, Iron County (coal)
P. Averitt (D)

Utah—Continued
Mineral resources—Continued
*Southern Kolob Terrace coal field
W. B. Cashion (D)
*Unita Basin oil shale
W. B. Cashion (D)
Engineering geology and geophysical studies:
*Geologic factors related to coal mine bumps
F. W. Osterwald (D)
*Upper Green River Valley (construction-site planning)
W. R. Hansen (D)
*Surficial geology of the Oak City area (construction-site planning)
D. J. Varnes (D)
Salt anticlines, Paradox Basin, Colorado and Utah (test-site evaluation)
D. P. Elston (D)
Salt anticline studies, Colorado and Utah (test-site evaluation)
E. M. Shoemaker (M)
Colorado Plateau regional geophysical studies
H. R. Joesting (W)
Great Basin geophysical studies
D. R. Mabey (M)

Vermont:
*Talc and asbestos deposits of north-central Vermont
W. M. Cady (Montpelier, Vt.)
Correlation of aeromagnetic studies and areal geology
R. W. Bromery (W)

Virginia:
*Petrology of the Manassas quadrangle
C. Milton (W)
*Potomac Basin studies, Maryland, Virginia, and West Virginia
J. T. Hack (W)
*Geology of the southern Appalachian folded belt, Kentucky, Tennessee and Virginia
L. D. Harris (W)
Origin and depositional control of some Tennessee and Virginia zinc deposits
H. Wedow, Jr. (Knoxville, Tenn.)
Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Petroleum geology of Duffield, Stickleyville, Keokee, Olinger, and Pennington Gap quadrangles, Virginia and Kentucky
L. D. Harris (W)
*Herndon quadrangle (construction-site planning)
R. E. Eggleton (D)
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
R. B. Guillou (W)
Aeromagnetic studies, Middlesboro-Morristown area, Tennessee, Kentucky, and Virginia
R. W. Johnson, Jr. (Knoxville, Tenn.)
Aeromagnetic studies of Shenandoah Valley dikes
R. W. Johnson (Knoxville, Tenn.)

Washington:
Foraminiferal studies of the Pacific Northwest
W. W. Rau (M)
*Republic quadrangle
R. L. Parker (D)

Washington—Continued
*Bald Knob quadrangle
M. H. Staatz (D)
*Grays Harbor basin
H. D. Gower (M)
*Northern Olympic Peninsula
R. D. Brown, Jr. (M)
*Holden and Lucerne quadrangles, Northern Cascade Mountains (copper)
F. W. Cater (D)
Metaline lead-zinc district
M. G. Dings (D)
*Stevens County lead-zinc district
R. G. Yates (M)
*Greenacres quadrangle, Washington-Idaho (high-alumina clays)
P. L. Weis (Spokane, Wash.)
*Hunter quadrangle (magnesite, tungsten, base metals, and barite)
A. B. Campbell (D)
*Chewelah area (magnesite)
Ian Campbell (San Francisco, Calif.)
*Mt. Spokane quadrangle (uranium)
A. E. Weissenborn (Spokane, Wash.)
*Turtle Lake quadrangle (uranium)
G. E. Becraft (W)
Coal resources
H. D. Gower (M)
*Maple Valley, Hobart, and Cumberland quadrangles, King County (coal)
A. A. Wanek (M)
*Puget Sound Basin (urban geology and construction-site planning)
D. R. Crandell (D)
Osceola mudflow studies
D. R. Crandell (D)
*Portland industrial area, Oregon and Washington (urban geology)
D. E. Trimble (D)
Aerial radiological monitoring surveys, Hanford
R. G. Schmidt (W)
Pacific Northwest geophysical studies
D. J. Stuart (M)

West Virginia:
*Potomac Basin studies, Maryland, Virginia, and West Virginia
J. T. Hack (W)
Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
R. B. Guillou (W)

Wisconsin:
*Florence County (iron)
C. E. Dutton (Madison, Wis.)
*Wisconsin zinc-lead mining district
T. E. Mullens (D)
*Stratigraphy of the lead-zinc district near Dubuque
J. W. Whitlow (W)
Geophysical studies in the Lake Superior region
G. D. Bath (M)
Correlation of aeromagnetic studies and areal geology, Florence County
R. W. Johnson, Jr. (Knoxville, Tenn.)

Wisconsin—Continued
Correlation of aeromagnetic studies and areal geology near Wausau
J. W. Allingham (W)

Wyoming:
General geology and engineering geology:
Devonian stratigraphy of the middle Rocky Mountain area, Colorado and adjacent States
V. E. Swanson (D)
Pennsylvanian and Permian stratigraphy, Rocky Mountain Front Range, Colorado and Wyoming
E. K. Maughan (D)
Investigation of Jurassic stratigraphy, south-central Wyoming and northwestern Colorado
G. N. Pipiringos (D)
Regional marine-nonmarine Upper Cretaceous facies relationships
J. F. Murphy (D)
Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming and Nebraska
H. A. Tourtelot (D)
*Quaternary geology of the Wind River Mountains
G. M. Richmond (D)
Structural significance of Reef Creek and Heart Mountain detachment faults
W. G. Pierce (M)
*Clark Fork area
W. G. Pierce (M)
*Geology of Grand Teton National Park
J. D. Love (Laramie, Wyo.)
*Cokeville quadrangle
W. W. Rubey (W)
Fossil Basin, southwest Wyoming
J. J. Tracey, Jr. (W)
*Fort Hill quadrangle
S. S. Oriel (D)
Geology and paleolimnology of the Green River formation
W. H. Bradley (W)
Mineralogy and geochemistry of the Green River formation
C. Milton (W)
*Storm Hill quadrangle
G. A. Izett (D)
*Upper Green River valley (construction-site planning)
W. R. Hansen (D)

Mineral resources:
*Atlantic City district (iron, gold)
R. W. Bayley (M)
Titaniferous black sands in Upper Cretaceous rocks
R. S. Houston (Laramie, Wyo.)
Geochemistry and petrology of western phosphate deposits
R. A. Gulbrandsen (M)
Stratigraphy and resources of Permian rocks in western Wyoming (phosphate, minor elements)
R. P. Sheldon (D)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota, and South Dakota
C. A. Sandberg (D)
*Shotgun Butte (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Crowheart Butte area (oil and gas)
J. F. Murphy (D)

Wyoming—Continued
Mineral resources—Continued
*Beaver Divide area (oil and gas)
F. B. Van Houten (Princeton, N.J.)
Regional geology of the Wind River Basin (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Whalen-Wheatland area (oil and gas)
L. W. McGrew (Laramie, Wyo.)
Reconnaissance geology of the Burney-Broadus coal field, Wyoming and Montana
W. W. Olive (W)
*Buffalo-Lake de Smet area (coal)
W. J. Mapel (D)
*Green River formation, Sweetwater County (oil shale, salines)
W. C. Culbertson (D)
Geophysical studies in uranium geology
R. M. Hazlewood (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
Uranium and phosphate in the Green River formation
W. R. Keefer (Laramie, Wyo.)
*Strawberry Hill quadrangle (uranium)
R. E. Davis (D)
Shirley basin area (uranium)
E. N. Harshman (D)
*Western Red Desert area (uranium in coal)
G. N. Pipiringos (D)
*Gas Hills district (uranium)
H. D. Zeller (D)
*Southern Powder River Basin (uranium)
W. N. Sharp (D)
*Pumpkin Buttes area, Powder River Basin (uranium)
W. N. Sharp (D)
*Crooks Gap area, Fremont County (uranium)
J. G. Stephens (D)
*Hulett Creek area (uranium)
C. S. Robinson (D)
*Hiland-Clarkson Hills area (uranium)
E. I. Rich (M)
*Regional stratigraphic study of the Inyan Kara group, Black Hills (uranium)
W. J. Mapel (D)

Puerto Rico and Canal Zone:
Cenozoic faunas, Caribbean area
W. P. Woodring (W)
Recent Foraminifera, Central America
P. J. Smith (M)
*Geology and mineral resources
W. H. Monroe (San Juan, Puerto Rico)

Western Pacific Islands:
Thermal and seismic studies in the South Pacific
J. H. Swartz (W)
Pacific Islands vegetation
F. R. Fosberg (W)
Cenozoic invertebrates, Pacific Islands
M. R. Todd (W)
Cenozoic invertebrates, mollusks, Pacific Islands
H. S. Ladd (W)

Western Pacific Islands—Continued
Oligocene gastropods and pelecypods, Pacific Islands
F. S. MacNeil (M)
Vertebrate faunas, Ishigaki, Ryukyu Islands
F. C. Whitmore, Jr., (W)
Ecologic studies on Onotoa Atoll
P. E. Cloud (W)
*Tinian
D. B. Doan (W)
*Truk
J. T. Stark (Recife, Brazil)
*Yap and Caroline Islands
C. G. Johnson (Honolulu, Hawaii)
*Palau Islands
G. Corwin (W)
*Pagan Island
G. Corwin (W)
*Okinawa
G. Corwin (W)
*Miyako Archipelago, Ryukyu Islands
D. B. Doan (W)
*Ishigaki, Ryukyu Islands
H. L. Foster (W)
*Guam
J. I. Tracey, Jr. (W)
*Saipan
P. E. Cloud (W)
*Bikini and nearby atolls
H. S. Ladd (W)

Antarctica:
Geology of Antarctica
E. L. Boudette (W)

Foreign:
Argentina—development of government geological services (training)
W. W. Olive (W)
Brazil—geological education
A. J. Bodenlos (Rio de Janeiro, Brazil)
*Brazil—iron and manganese resources, Minas Gerais
J. V. N. Dorr II (Belo Horizonte, Brazil)
*Brazil—base-metal resources
A. J. Bodenlos (Rio de Janeiro, Brazil)
Brazil—uranium resources (training)
C. T. Pierson (Rio de Janeiro, Brazil)
Bolivia—mineral resources and geologic mapping (advisory and training)
T. H. Kiilsgaard (W)
**Chile—mineral resources and national geologic mapping
W. D. Carter (Santiago, Chile)
**Surficial geology, eastern Greenland (construction-site planning)
W. E. Davies (W)
India—mineral resources (advisory)
L. V. Blade (Calcutta, India)
Indonesia—economic and engineering geology (advisory and training)
D. A. Andrews (Bandung, Indonesia)
Jordan—mineral resources development (advisory)
V. E. McKelvey (M)
**Libya—industrial minerals and national geologic map
G. H. Goudarzi (Tripoli, Libya)

Foreign—Continued
Mexico—regional geologic mapping (training)
R. L. Miller (Mexico D. F., Mex.)
Pakistan—mineral resources development (advisory and training)
J. A. Reinemund (Quetta, Pakistan)
Peru—economic geology, Southern provinces (advisory)
W. W. Olive (W)
**Philippines—iron, chromite and non-metallic mineral resources
J. F. Harrington (Manila, P. I.)
**Saudi Arabia—national geologic map
G. F. Brown (Jidda, Saudi Arabia)

Foreign—Continued
Thailand—economic geology and mineral industry expansion (advisory)
L. S. Gardner (Bangkok, Thailand)
*Taiwan—economic geology (training)
S. Rosenblum (Taipei, Taiwan)
Turkey—University of Istanbul (training)
Q. D. Singewald (Istanbul, Turkey)
Extraterrestrial:
Investigations of lunar craters
E. M. Shoemaker (M)
Photogeology of the moon
R. J. Hackman (W)

TOPICAL INVESTIGATIONS

Heavy metals:
District studies:
Ferrous and ferro-alloy metals:
*Selected iron deposits of the Northeastern States
A. F. Buddington (Princeton, N.J.)
Correlation of aeromagnetic studies and areal geology, Adirondacks area, New York (iron)
J. R. Balsley (W)
Correlation of aeromagnetic studies and areal geology, New York-New Jersey Highlands (iron)
A. Jespersen (W)
Clinton iron ores of the Southern Appalachians
R. P. Sheldon (D)
*Iron River-Crystal Falls district, Michigan (iron)
H. L. James (M)
*Eastern Iron County, Michigan (iron)
K. L. Wier (Iron Mountain, Mich.)
*Southern Dickinson County, Michigan (iron)
R. W. Bayley (M)
*East Marquette district, Michigan (iron)
J. E. Gair (D)
*Florence County, Wisconsin (iron)
C. E. Dutton (Madison, Wis.)
*Cuyuna North Range, Minnesota (iron)
R. G. Schmidt (W)
Iron ore deposits of Nevada
R. G. Reeves (M)
*Atlantic City district, Wyoming (iron, gold)
R. W. Bayley (M)
*Unionville and Buffalo Mountain quadrangles, Humbolt Range, Nevada (iron, tungsten, silver, quicksilver)
R. E. Wallace (M)
**Klukwan iron district, Alaska
E. C. Robertson (W)
*Bridgewater quadrangle, Maine (manganese)
L. Pavlides (W)
Manganese deposits of the Philipsburg area, Montana (manganese and base metals)
W. C. Prinz (Spokane, Wash.)
*John Day area, Oregon (chromite)
T. P. Thayer (W)
Lateritic nickel deposits of the Klamath Mountains, Oregon-California.
P. E. Hotz (M)
*Hamme tungsten deposit, North Carolina
J. M. Parker III (Raleigh, N.C.)

Heavy metals—Continued
District studies—Continued
Ferrous and ferro-alloy metals—Continued
*San Francisco Mountains, Utah (tungsten, copper)
D. M. Lemmon (M)
*Wheeler Peak and Garrison quadrangles, Snake Range, Nevada-Utah (tungsten, beryllium)
D. H. Whitebread (M)
*Osgood Mountains quadrangle, Nevada (tungsten, quicksilver)
P. E. Hotz (M)
*Bishop tungsten district, California
P. C. Bateman (M)
*Eastern Sierra tungsten area, California; Devil's Postpile, Mt. Morrison, and Casa Diablo quadrangles (tungsten, base metals)
C. D. Rinehart (M)
*Geologic study of the Sierra Nevada batholith, California (tungsten, gold, base metals)
P. C. Bateman (M)
*Blackbird Mountain area, Idaho (cobalt)
J. S. Vhay (Spokane, Wash.)
*Thunder Mountain niobium area, Montana-Idaho
R. L. Parker (D)
Magnet Cove niobium investigations, Arkansas
L. V. Blade (D)
Base and precious metals:
*Swain County copper district, North Carolina
G. H. Espenshade (W)
Massive sulfide deposits of the Ducktown district, Tennessee and adjacent areas (copper, iron, sulfur)
R. M. Hernon (D)
*Michigan copper district
W. S. White (W)
*Central district, New Mexico (copper, zinc)
W. R. Jones (D)
*Klondyke quadrangle, Arizona (copper)
F. S. Simons (D)
*Bradshaw Mountains, Arizona (copper)
C. A. Anderson (W)
*Christmas quadrangle, Arizona (copper, iron)
C. R. Willden (M)
*Globe-Miami area, Arizona (copper)
N. P. Peterson (Globe, Ariz.)
*Prescott-Paulden area, Arizona (copper)
M. H. Krieger (M)
*Mammoth quadrangle, Arizona (copper)
S. C. Creasey (M)

Heavy metals—Continued
District studies—Continued
Base and precious metals—Continued
*Twin Buttes, area, Arizona (copper)
J. R. Cooper (D)
*Contact-metamorphic deposits of the Little Dragoons area, Arizona (copper)
J. R. Cooper (D)
Structural geology of the Sierra foothills mineral belt, California (copper, zinc, gold, chromite)
L. D. Clark (M)
*Holden and Lucerne quadrangles, Northern Cascade Mountains, Washington (copper)
F. W. Cater (D)
*Regional geologic setting of the Bingham Canyon district, Utah (copper)
R. J. Roberts (M)
*Lyon, Douglas, and Ormsby Counties, Nevada (copper)
J. G. Moore (M)
*Regional geologic setting of the Ely district, Nevada (copper, lead, zinc)
A. L. Brokaw (D)
**Southern Brooks Range, Alaska (copper, precious metals)
W. P. Brosgé (M)
*Antler Peak quadrangle, Nevada (base and precious metals)
R. J. Roberts (M)
*Eureka County, Nevada (base and precious metals)
R. J. Roberts (M)
*Creede and Summitville districts, Colorado (base and precious metals, and fluorspar)
T. A. Steven (D)
*East Tennessee zinc studies
A. L. Brokaw (D)
Origin and depositional control of some Tennessee and Virginia zinc deposits
H. Wedow, Jr. (Knoxville, Tenn.)
*Wisconsin zinc-lead mining district
T. E. Mullens (D)
*Stratigraphy of the lead-zinc district near Dubuque, Iowa
J. W. Whitlow (W)
*Tri-State lead-zinc district, Oklahoma, Missouri, Kansas
E. T. McKnight (W)
*Holy Cross quadrangle, Colorado, and the Colorado mineral belt (lead, zinc, silver, copper, gold)
O. Tweto (D)
*Tenmile Range, including the Kokomo mining district, Colorado (base and precious metals)
A. H. Koschmann (D)
*Central City-Georgetown area, Colorado, including studies of the Precambrian history of the Front Range (base, precious, and radioactive metals)
P. K. Sims (D)
*Minturn quadrangle, Colorado (zinc, silver, copper, lead, gold)
T. S. Lovering (D)
*Rico district, Colorado (lead, zinc, silver)
E. T. McKnight (W)
*San Juan mining area, Colorado, including detailed study of the Silverton Caldera (lead, zinc, silver, gold, copper)
R. G. Luedke (W)
*Alta quadrangle, Utah (lead, silver, phosphate rock)
M. D. Crittenden, Jr. (M)

Heavy metals—Continued
District studies—Continued
Base and precious metals—Continued
*East Tintic lead-zinc district, Utah, including extensive geochemical studies
H. T. Morris (M)
*Eureka area, Nevada (zinc, lead, silver, gold)
T. B. Nolan (W)
Ione quadrangle, Nevada (lead, quicksilver, tungsten)
C. J. Vitaliano (Bloomington, Ind.)
*Boulder batholith area, Montana (base, precious, and radioactive metals)
M. R. Klepper (W)
Ore deposits of the Coeur d'Alene mining district, Idaho (lead, zinc, silver)
V. C. Fryklund, Jr. (Spokane, Wash.)
*General geology of the Coeur d'Alene mining district, Idaho (lead, zinc, silver)
A. B. Griggs (M)
*Cerro Gordo quadrangle, California (lead, zinc)
W. C. Smith (M)
*Panamint Butte quadrangle, California, including special geochemical studies (lead-silver)
W. E. Hall (W)
*Metaline lead-zinc district, Washington
M. G. Dings (D)
*Stevens County, Washington, lead-zinc district
R. G. Yates (M)
*Mt. Diablo area, California (quicksilver, copper, gold, silver)
E. H. Pampeyan (M)
*Ochoco Reservation, Lookout Mountain, Eagle Rock, and Post quadrangles, Oregon (quicksilver)
A. C. Waters (Baltimore, Md.)
**Lower Kuskokwim-Bristol Bay region, Alaska (quicksilver, antimony, zinc)
J. M. Hoare (M)
Quicksilver deposits, southwestern Alaska
E. M. MacKevett, Jr. (M)
*Nome C-1 and D-1 quadrangles, Alaska (gold)
C. L. Hummel (M)
*Tofty placer district, Alaska (gold, tin)
D. M. Hopkins (M)
**Regional geology and mineral resources, southeastern Alaska
E. H. Lathram (M)
Seward Peninsula tin investigations, Alaska
P. L. Killeen (W)
Commodity and topical studies:
Resource study and appraisal of ferrous and ferro-alloy metals
T. P. Thayer (W)
Tungsten resource studies
O. Tweto (D)
Cobalt resource studies
J. S. Vhay (Spokane, Wash.)
Resources and geochemistry of rare-earth elements of the Western States
J. W. Adams (D)
Resource study and appraisal of base and precious metals
A. R. Kinkel, Jr. (W)
Lead-zinc-silver resource studies
E. T. McKnight (W)
Gold resource studies
A. H. Koschmann (D)

Heavy metals—Continued
- Commodity and topical studies—Continued
  - Ore deposition at Creede, Colorado
    - E. W. Roedder (W)
  - Origin of the Mississippi Valley type ore deposits
    - A. V. Heyl (W)
  - Western oxidized zinc deposits
    - A. V. Heyl (W)
  - Geophysical studies of relation of ore deposits to metamorphism
    - A. Griscom (W)
  - Alaskan metallogenic provinces
    - C. L. Sainsbury (M)

Light metals and industrial minerals:
- District studies:
  - Titaniferous black sands in Upper Cretaceous rocks, Wyoming
    - R. S. Houston (Laramie, Wyo.)
  - Distribution and origin of the Kauai bauxite deposits, Hawaii
    - S. H. Patterson (Lihue, Kauai, Hawaii)
  - Bauxite deposits of the Southeastern States
    - E. F. Overstreet (W)
  - Aeromagnetic studies in the Newport, Arkansas, and Ozark bauxite areas
    - A. Jespersen (W)
  - *Marysvale district, Utah (alunite)
    - R. L. Parker (D)
  - *Greenacres quadrangle, Washington-Idaho (high-alumina clays)
    - P. L. Weis (Spokane, Wash.)
  - *Hunter quadrangle, Washington (magnesite, tungsten, base metals, barite)
    - A. B. Campbell (D)
  - *Chewelah area, Washington (magnesite)
    - Ian Campbell (San Francisco, Calif.)
  - *Lake George district, Colorado (beryllium)
    - C. C. Hawley (D)
  - Pegmatites of the Spruce Pine and Franklin-Sylva districts, North Carolina
    - F. G. Lesure (Knoville, Tenn.)
  - *Geologic setting of the Spruce Pine pegmatite district, North Carolina (mica, feldspar)
    - D. A. Brobst (D)
  - *Southern Black Hills, South Dakota (pegmatite minerals)
    - J. J. Norton (D)
  - Fluorspar deposits of northwestern Kentucky
    - R. D. Trace (W)
  - *Salem quadrangle, Kentucky (fluorspar)
    - R. D. Trace (W)
  - *Poncha Springs and Saguache quadrangles, Colorado (fluorspar)
    - R. E. Van Alstine (W)
  - *Thomas and Dugway Ranges, Utah (fluorspar, uranium, beryllium)
    - M. H. Staatz (D)
  - *Geology and ore deposits of Bullfrog, and Bear Mountain quadrangles, Nevada (fluorspar, bentonite, gold, silver)
    - H. R. Cornwall (M)
  - *Talc and asbestos deposits of north-central Vermont
    - W. M. Cady (Montpelier, Vt.)
  - *Gouverneur district, New York (talc)
    - A. E. J. Engel (Pasadena, Calif.)

Light metals and industrial minerals—Continued
- District studies—Continued
  - *MacFadden Peak quadrangle and adjacent areas, Arizona (asbestos)
    - A. F. Shride (D)
  - Barite deposits of Arkansas
    - D. A. Brobst (D)
  - Clay deposits of Maryland
    - M. M. Knechtel (W)
  - Clay deposits of the Olive Hill bed of eastern Kentucky
    - J. W. Hosterman (W)
  - Clay studies, Colorado Plateau
    - L. G. Schultz (D)
  - *Western Mojave Desert, California (boron)
    - T. W. Dibblee, Jr. (M)
  - *Furnace Creek area, California (boron)
    - J. F. McAllister (M)
  - Origin of the borate-bearing marsh deposits of California, Oregon, and Nevada (boron)
    - W. C. Smith (M)
  - *Geology and origin of the saline deposits of Searles Lake, California
    - G. I. Smith (M)
  - Potash and other saline deposits of the Carlsbad area, New Mexico
    - C. L. Jones (M)
  - Phosphate deposits of northern Florida
    - G. H. Espenshade (W)
  - *Florida land-pebble phosphate deposits
    - J. B. Cathcart (D)
  - Stratigraphy and resources of Permian rocks in western Montana (phosphate, minor elements)
    - R. W. Swanson (Spokane, Wash.)
  - Stratigraphy and resources of Permian rocks in southwestern Montana (phosphate, minor elements)
    - E. R. Cressman (M)
  - *Morrison Lake quadrangle, Idaho-Montana (phosphate)
    - E. R. Cressman (M)
  - Stratigraphy and resources of Permian rocks in western Wyoming (phosphate, minor elements)
    - R. P. Sheldon (D)
  - *Irwin quadrangle, Caribou Mountains, Idaho (phosphate)
    - L. S. Gardner (Bangkok, Thailand)
  - *Soda Springs quadrangle, Idaho, including studies of the Bannock thrust zone (phosphate)
    - F. C. Armstrong (Spokane Wash.)
  - *Aspen Range-Dry Ridge area, Idaho (phosphate)
    - T. M. Cheney (M)
  - Stratigraphy and resources of the Phosphoria formation in Idaho (phosphate, minor elements)
    - V. E. McKelvey (M)
  - Stratigraphy and resources of the Phosphoria and Park City formations in Utah and Nevada (phosphate, minor elements)
    - T. M. Cheney (W)
  - *Heceta-Tuxekan area, Alaska (high-calcium limestone)
    - G. D. Eberlein (M)
- Commodity and topical studies:
  - Resources and geochemistry of selenium in the United States
    - D. F. Davidson (D)
  - Resource study and appraisal of igneous and metamorphic minerals and light metals
    - T. P. Thayer (W)

Light metals and industrial minerals—Continued
Commodity and topical studies—Continued
Pegmatite-mineral resource studies
J. J. Norton (D)
Resource study and appraisals of sedimentary nonmetallic minerals
C. L. Rogers (W)
Phosphate reserves, Southeastern United States
J. B. Cathcart (D)
Geochemistry and petrology of western phosphate deposits
R. A. Gulbrandsen (M)
Phosphate deposits of south-central Montana
R. W. Swanson (Spokane, Wash.)

Radioactive minerals:
District studies:
Granites and related rocks of the Southeastern States, with emphasis on monazite and xenotime
J. B. Mertie, Jr. (W)
Geology of the Piedmont region of the Southeastern States; with emphasis on the origin and distribution of monazite
W. C. Overstreet (W)
*Western San Juan Mountains, Colorado (uranium, vanadium, gold)
C. S. Bromfield (D)
Selected studies of uranium and rare-earth deposits in Pennsylvania and New Jersey
H. Klemic (W)
*Lehighton quadrangle, Pennsylvania (uranium)
H. Klemic (W)
*Shelby quadrangle, North Carolina (monazite)
W. C. Overstreet (W)
Mineralogy of uranium-bearing rocks in Karnes and Duval Counties, Texas
A. D. Weeks (W)
*Harding County, South Dakota, and adjacent areas (uraniferous lignite)
G. N. Pipiringos (D)
*Southern Black Hills, South Dakota (uranium)
G. B. Gott (D)
Regional gravity studies in uranium geology, Black Hills area
R. M. Hazlewood (D)
*Regional stratigraphic study of the Inyan Kara group, Black Hills, Wyoming (uranium)
W. J. Mapel (D)
*Hulett Creek area, Wyoming (uranium)
C. S. Robinson (D)
*Hiland-Clarkson Hills area, Wyoming (uranium)
E. I. Rich (M)
*Pumpkin Buttes area, Powder River Basin, Wyoming (uranium)
W. N. Sharp (D)
*Southern Powder River Basin, Wyoming (uranium)
W. N. Sharp (D)
*Strawberry Hill quadrangle, Wyoming (uranium)
R. E. Davis (D)
Shirley basin area, Wyoming (uranium)
E. N. Harshman (D)
*Gas Hills district, Wyoming (uranium)
H. D. Zeller (D)
*Crooks Gap area, Fremont County, Wyoming (uranium)
J. G. Stephens (D)

Radioactive minerals—Continued
District studies—Continued
*Western Red Desert area, Wyoming (uranium in coal)
G. N. Pipiringos (D)
Uranium and phosphate in the Green River formation, Wyoming
W. R. Keefer (Laramie, Wyo.)
*Baggs area, Wyoming and Colorado (uranium)
G. E. Prichard (D)
*Powderhorn area, Gunnison County, Colorado (thorium)
J. C. Olson (D)
*Wet Mountains, Colorado (thorium, base and precious metals)
M. R. Brock (W)
*Maybell-Lay area, Moffat County, Colorado (uranium)
M. J. Bergin (W)
*Compilation of Colorado Plateau geologic maps (uranium, vanadium)
D. G. Wyant (D)
Stratigraphic studies, Colorado Plateau (uranium, vanadium)
L. C. Craig (D)
San Rafael group stratigraphy, Colorado Plateau (uranium)
J. C. Wright (D)
Triassic stratigraphy and lithology of the Colorado Plateau (uranium, copper)
J. H. Stewart (D)
Relative concentrations of chemical elements in rocks and ore deposits of the Colorado Plateau (uranium, vanadium, copper)
A. T. Miesch (D)
Colorado Plateau botanical prospecting studies
F. J. Kleinhampl (M)
Colorado Plateau ground-water studies (uranium)
D. Jobin (D)
*La Sal area, Utah-Colorado (uranium, vanadium)
W. D. Carter (Santiago, Chile)
*Lisbon Valley area, Utah-Colorado (uranium, vanadium, copper)
G. W. Weir (M)
*Ralston Buttes, Colorado (uranium)
D. M. Sheridan (D)
*Klondike Ridge area, Colorado (uranium, copper, manganese, salines)
J. D. Vogel (D)
Uravan district, Colorado (vanadium, uranium)
R. L. Boardman (W)
Wallrock alteration and its relation to thorium deposition in the Wet Mountains, Colorado
E. S. Larsen, 3d (W)
*Slick Rock district, Colorado (uranium, vanadium)
D. R. Shawe (D)
Exploration for uranium deposits in the Gypsum Valley district, Colorado
C. F. Withington (W)
*Bull Canyon district, Colorado (vanadium, uranium)
D. Elston (D)
*Ute Mountains, Colorado (uranium, vanadium)
E. B. Ekren (D)
*Abajo Mountains, Utah (uranium, vanadium)
I. J. Witkind (D)
*White Canyon area, Utah (uranium, copper)
R. E. Thaden (D)

Radioactive minerals—Continued
District studies—Continued
*Deer Flat area, White Canyon district, Utah (uranium, copper)
T. L. Finnel (D)
*Elk Ridge area, Utah (uranium)
R. Q. Lewis (D)
Uranium ore controls of the San Rafael Swell, Utah
C. C. Hawley (D)
*Sage Plain area, Utah (uranium and vanadium)
L. C. Huff (D)
*Orange Cliffs area, Utah (uranium)
F. A. McKeown (D)
*Moab-Interriver area, east-central Utah (uranium)
E. N. Hinrichs (D)
*Circle Cliffs area, Utah (uranium)
E. S. Davidson (Tucson, Ariz.)
Regional relations of the uranium deposits of northwestern New Mexico
L. S. Hilpert (Salt Lake City, Utah)
Mineralogy of uranium-bearing rocks in the Grants area, New Mexico
A. D. Weeks (W)
*Grants area, New Mexico (uranium)
R. E. Thaden (D)
*Laguna district, New Mexico (uranium)
R. H. Moench (D)
Ambrosia Lake district, New Mexico (uranium)
H. C. Granger (D)
*Tucumcari-Sabinoso area, New Mexico (uranium)
R. L. Griggs (D)
*Carrizo Mountains area, Arizona-New Mexico (uranium)
J. D. Strobell (D)
Studies of uranium deposits in Arizona
R. B. Raup (D)
*East Vermillion Cliffs area, Arizona (uranium, vanadium)
R. G. Peterson (Boston, Mass.)
Uranium deposits of the Dripping Spring quartzite of southeastern Arizona
H. C. Granger (D)
*Radioactive placer deposits of central Idaho
D. L. Schmidt (Seattle, Wash.)
*Mt. Spokane quadrangle, Washington (uranium)
A. E. Weissenborn (Spokane, Wash.)
*Turtle Lake quadrangle, Washington (uranium)
G. E. Becraft (W)
Commodity and topical studies:
Resource studies and appraisals of uranium and thorium deposits
A. P. Butler (D)
Uranium in natural waters
P. W. Fix (W)
Geology of uranium in coaly rocks in the United States
J. D. Vine (M)
Distribution of metals in asphaltite and petroleum (uranium)
W. J. Hail (D)
Relation of fossil wood to uranium deposits, with emphasis on the Colorado Plateau
R. A. Scott (D)
Formation and redistribution of uranium deposits of the Colorado Plateau and Wyoming
K. G. Bell (D)

Radioactive minerals—Continued
Commodity and topical studies—Continued
Uranium-vanadium deposits in sandstone, with emphasis on the Colorado Plateau
R. P. Fischer (D)
Geology of uranium in lignites, Montana, North Dakota, and South Dakota
N. M. Denson (D)
Trace elements in rocks of Pennsylvanian age, Oklahoma, Kansas, Missouri (uranium, phosphate)
W. Danilchik (Quetta, Pakistan)
Uranium-thorium reconnaissance, Alaska
E. M. MacKevett, Jr. (M)

Fuels:
District studies:
Petroleum and natural gas:
*Stratigraphy of the Dunkirk and related beds in the Penn Yan and Keuka Lake quadrangles, New York (oil and gas)
M. J. Bergin (W)
*Stratigraphy of the Dunkirk and related beds, in the Bath and Woodhull quadrangles, New York (oil and gas)
J. F. Pepper (New Philadelphia, Ohio)
*Petroleum geology of Duffield, Stickleyville, Keokee, Olinger, and Pennington Gap quadrangles, Virginia and Kentucky
L. D. Harris (W)
*Northern Arkansas oil and gas investigations, Arkansas
E. E. Glick (D)
Anadarko Basin, Oklahoma and Texas (oil and gas)
W. L. Adkison (Lawrence, Kans.)
McAlester Basin, Oklahoma (oil and gas)
S. E. Frezon (D)
Central Nebraska basin (oil and gas)
G. E. Prichard (D)
Subsurface geology of Dakota sandstone, Colorado and Nebraska (oil and gas)
N. W. Bass (D)
Paleozoic stratigraphy of the Sedgwick Basin, Kansas (oil and gas)
W. L. Adkison (Lawrence, Kans.)
*Wilson County, Kansas (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
*Shawnee County, Kansas (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
*Pennsylvanian oil and gas investigation, Texas
D. A. Myers (D)
*Stratigraphy, Northern Franklin Mountains, west Texas (petroleum)
R. L. Harbour (D)
Oil and gas fields, New Mexico
D. C. Duncan (W)
*Fuels potential of the Navajo Reservation, Arizona and Utah
R. B. O'Sullivan (D)
*Geology of the Winnett-Mosby area, Montana (oil and gas)
W. D. Johnson, Jr. (Lawrence, Kans.)
Williston Basin oil and gas studies, Wyoming, Montana, North Dakota and South Dakota
C. A. Sandberg (D)
*Beaver Divide area, Wyoming (oil and gas)
F. B. Van Houten (Princeton, N.J.)

Fuels—Continued
District studies—Continued
Petroleum and natural gas—Continued
*Crowheart Butte area, Wyoming (oil and gas)
J. F. Murphy (D)
*Shotgun Butte, Wyoming (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Whalen-Wheatland area, Wyoming (oil and gas)
L.W. McGrew (Laramie, Wyo.)
Regional geology of the Wind River Basin, Wyoming (oil and gas)
W. R. Keefer (Laramie, Wyo.)
*Eastern Los Angeles basin, California (petroleum)
J. E. Schoellhamer (M)
Rocks and structures of the Los Angeles basin and their gravitational effects
T. H. McCulloh (Riverside, Calif.)
*Southeastern Ventura Basin, California (petroleum)
E. L. Winterer (Los Angeles, Calif.)
*Northwest Sacramento Valley, California (petroleum)
R. D. Brown, Jr. (M)
*Newport embayment, Oregon (oil and gas)
P. D. Snavely, Jr. (M)
*Anlauf and Drain quadrangles, Oregon (oil and gas)
L. Hoover (W)
**Nelchina area, Alaska (petroleum)
A. Grantz (M)
*Iniskin-Tuxedni region, Alaska (petroleum)
R. L. Detterman (M)
**Gulf of Alaska province, Alaska (petroleum)
D. J. Miller (M)
**Buckland and Huslia Rivers area, west-central Alaska
W. W. Patton, Jr. (M)
**Stratigraphic and structural studies of the Lower Yukon-Koyukuk area, Alaska (petroleum)
W. W. Patton, Jr. (M)
**Northern Alaska petroleum investigations
G. Gryc (W)
Coal:
*Western middle anthracite coal field, Pennsylvania
H. H. Arndt (W)
*Southern anthracite field, Pennsylvania
G. H. Wood, Jr. (W)
*Geology in the vicinity of anthracite mine drainage projects, Pennsylvania
T. M. Kehn (Mt. Carmel, Pa.)
*Allegany County, Maryland (coal)
W. de Witt, Jr. (W)
*Warrior quadrangle, Alabama (coal)
W. C. Culbertson (D)
*Geology and coal resources of Belmont County, Ohio
H. L. Berryhill, Jr. (D)
*Eastern Kentucky coal investigations
J. W. Huddle (W)
*Ivydell, Pioneer, Jellico West, and Ketchen quadrangles Tennessee (coal)
K. J. Englund (W)
*Geology and coal deposits, Terre Haute and Dennison quadrangles, Indiana
P. Averitt (D)
*Arkansas Basin (coal)
B. R. Haley (D)

Fuels—Continued
District studies—Continued
Coal—Continued
*Ft. Smith District, Arkansas and Oklahoma (coal and gas)
T. A. Hendricks (D)
*Geology of the Livingston-Trail Creek area, Montana (coal)
A. E. Roberts (D)
Reconnaissance geology of the Burney-Broadus coal field, Wyoming and Montana
W. W. Olive (W)
*Buffalo-Lake de Smet area, Wyoming (coal)
W. J. Mapel (D)
*North Park, Colorado (coal, oil, and gas)
D. M. Kinney (W)
*Western North Park, Colorado (coal, oil, and gas)
W. J. Hail (D)
*Carbondale coal field, Colorado
J. R. Donnell (D)
*Trinidad coal field, Colorado
R. B. Johnson (D)
*Animas River area, Colorado and New Mexico (coal, oil, and gas)
H. Barnes (D)
*Raton Basin coking coal, New Mexico
A. A. Wanek (M)
*East side San Juan Basin, New Mexico (coal, oil and gas)
C. H. Dane (W)
*Cedar Mountain quadrangle, Iron County, Utah (coal)
P. Averitt (D)
*Southern Kolob Terrace coal field, Utah
W. B. Cashion (D)
*Maple Valley, Hobart and Cumberland quadrangles, King County, Washington (coal)
A. A. Wanek (M)
Matanuska stratigraphic studies, Alaska (coal)
A. Grantz (M)
*Matanuska coal field, Alaska
F. F. Barnes (M)
Tertiary history of the Yukon-Tanana Upland, Alaska (coal)
D. M. Hopkins (M)
*Nenana coal investigations, Alaska
C. Wahrhaftig (M)
Oil shale:
Oil shale investigations, eastern United States
L. C. Conant (Tripoli, Libya)
*Green River formation, Sweetwater County, Wyoming (oil shale, salines)
W. C. Culbertson (D)
**Oil shale investigations in Colorado
D. C. Duncan (W)
Oil shale resources, northwest Colorado
J. R. Donnell (D)
*Grand-Battlement Mesa oil-shale, Colorado
J. R. Donnell (D)
*Uinta Basin oil shale, Utah
W. B. Cashion (D)
Resource studies:
Fuel resource studies
D. C. Duncan (W)
Geology of the continental shelves
J. F. Pepper (New Philadelphia, Ohio)

Fuels—Continued
Resource studies—Continued
Synthesis of geologic data on Atlantic Coastal Plain and Continental Shelf
J. E. Johnston (W)
Coal resources of the United States
P. Averitt (D)
Coal fields of the United States
J. Trumbull (W)
*Bituminous coal resources of Pennsylvania
E. D. Patterson (W)
Coal resources of Alabama
W. C. Culbertson (D)
Coal resources of Washington
H. D. Gower (M)
Map of coal fields of Alaska
F. F. Barnes (M)

Geochemical and botanical exploration methods:
Dispersion pattern of minor elements related to igneous intrusions
W. R. Griffitts (D)
Hydrogeochemical prospecting
F. C. Canney (D)
Geochemical halos of mineral deposits, Basin and Range province
L. C. Huff (D)
Geochemical prospecting techniques, Alaska
R. M. Chapman (D)
Botanical exploration and research
H. L. Cannon (D)

Isotope geology in exploration:
Studies of isotope geology of lead
R. S. Cannon, Jr. (D)
Radon and helium studies
A. B. Tanner (Salt Lake City, Utah)
Isotopic fractionation of sulfur in geochemical processes
W. U. Ault (Hawaii)

Geophysical exploration methods:
Correlation of airborne radioactivity data and areal geology
R. B. Guillou (W)
Development of seismic and acoustic methods
W. H. Jackson (D)
Seismic noise and model studies
W. H. Jackson (D)
Magnetic model studies
I. Zietz (W)
Polar charts for 3-dimensional magnetic anomalies
R. G. Henderson (W)
Experimental aeromagnetic survey in northeast Oklahoma
I. Zietz (W)
Geophysical interpretation aids
I. Roman (W)
Downward continuation of magnetic and gravity anomalies
R. G. Henderson (W)
Telluric currents investigation
F. C. Frischknecht (D)
Development of electromagnetic methods
F. C. Frischknecht (D)
Electronics laboratory
W. W. Vaughn (D)

Geophysical exploration methods—Continued
Geophysical instrument shop
R. Raspet (W)

Exploration and mapping techniques:
Photogeology research
W. A. Fischer (W)
Photogeology training
C. L. Pillmore (W)
Photogeology service
R. G. Ray (W)

Geology applied to construction and terrain problems:
Research and application of geology and seismology to public works planning, Massachusetts
L.W. Currier (W)
*Dennis and Harwich quadrangles, Massachusetts, surficial geologic mapping and special seismic studies of engineering problems.
L. W. Currier (W)
Sea-cliff erosion studies
C. A. Kaye (Boston, Mass.)
*Herndon quadrangle, Virginia (construction-site planning)
R. E. Eggleton (D)
*Knoxville and vicinity, Tennessee (urban geology)
J. M. Cattermole (D)
*Omaha-Council Bluffs and vicinity, Nebraska and Iowa (urban geology)
R. D. Miller (D)
*Great Falls area, Montana (urban geology and construction-site planning)
R. W. Lemke (D)
*Fort Peck area, Montana (construction-site planning)
H. D. Varnes (D)
*Wolf Point area, Montana (construction-site planning)
R. B. Colton (D)
*Denver and vicinity; Golden and Morrison quadrangles, Colorado (urban geology)
R. Van Horn (D)
*Air Force Academy, Colorado (construction-site planning)
D. J. Varnes (D)
*Black Canyon of the Gunnison River, Colorado (construction-site planning)
W. R. Hansen (D)
*Upper Green River Valley, Utah (construction-site planning)
W. R. Hansen (D)
*Surficial geology of the Oak City area, Utah (construction-site planning)
D. J. Varnes (D)
*Surficial geology of the Beverly Hills, Venice, and Topanga quadrangles, Los Angeles, California (urban geology)
J. T. McGill (Los Angeles, Calif.)
*San Francisco Bay area; San Francisco South quadrangle, California (urban geology)
M. G. Bonilla (M)
*San Francisco Bay area; San Francisco North quadrangle, California (urban geology)
J. Schlocker (M)
*Oakland East quadrangle, California (urban geology)
D. H. Radbruch (M)

Geology applied to construction and terrain problems—Con.

*Portland industrial area, Oregon and Washington (urban geology)
D. E. Trimble (D)

*Puget Sound Basin, Washington (urban geology and construction-site planning)
D. R. Crandell (D)

*Anchorage and vicinity, Alaska (construction-site planning)
R. D. Miller (D)

*Mt. Hayes D–3 and D–4 quadrangles, Alaska (construction-site planning)
T. L. Péwé (College, Alaska)

*Surficial and engineering geology studies and construction materials sources, Alaska
T. L. Péwé (College, Alaska)

*Engineering geology of Talkeetna-McGrath highway, Alaska
T. L. Péwé (College, Alaska)

Engineering geology laboratory
T. C. Nichols, Jr. (D)

Engineering problems related to rock failure:

Landslide studies in the Fort Randall Reservoir area, South Dakota
H. D. Varnes (D)

Earthquake investigations, Hebgen Lake, Montana
J. B. Hadley (D)

*Geologic factors related to coal mine bumps, Utah
F. W. Osterwald (D)

Osceola mudflow studies, Washington
D. R. Crandell (D)

*Lituya Bay giant-wave investigation, Alaska
D. J. Miller (M)

Literature study of geologic factors involved in subsidence
A. S. Allen (W)

Nuclear test-site studies:

*Engineering geology of AEC Gnome Test Site, New Mexico
V. R. Wilmarth (D)

*Nash Draw quadrangle, New Mexico (test-site evaluation)
J. D. Vine (M)

Seismic studies, southern Eddy County, New Mexico (test-site evaluation)
P. E. Byerly (D)

Salt anticline studies, Colorado and Utah (test-site evaluation)
E. M. Shoemaker (M)

Salt anticlines, Paradox Basin, Colorado and Utah (test-site evaluation)
D. P. Elston (D)

Geophysical studies at the Nevada Test Site
W. H. Diment (D)

*Engineering geology of the AEC Nevada Test Site area
V. R. Wilmarth (D)

*Nuclear test-site evaluation, Chariot, Alaska
G. D. Eberlein (M)

*Nuclear test-site evaluation, Katalla, Alaska
G. D. Eberlein (M)

Radioactive waste disposal investigations:

Geochemical problems of radioactive waste disposal
H. H. Waesche (W)

Radioactive waste disposal investigations—Continued

Rock salt deposits of the United States
W. G. Pierce (M)

Geology of the Appalachian Basin with reference to disposal of high-level radioactive wastes
G.W. Colton (W)

Geology of the Michigan Basin with reference to disposal of high-level radioactive wastes
W. deWitt (W)

Geology of the San Juan and Central Valley Basins with reference to disposal of high-level radioactive wastes
C. A. Repenning (M)

Measurement of background radiation:

Aerial radiological monitoring surveys, Northeastern United States
P. Popenoe (W)

Aerial radiological monitoring surveys, Belvoir area, Virginia and Maryland
R. B. Guillou (W)

Aerial radiological monitoring surveys, Georgia Nuclear Aircraft Laboratory
J. A. MacKallor (W)

Aerial radiological monitoring surveys, Savannah River Plant, Georgia and South Carolina
R. G. Schmidt (W)

Aerial radiological monitoring surveys, Oak Ridge National Laboratory, Tennessee
R. G. Bates (W)

Aerial radiological monitoring surveys, Chicago, Illinois
R. B. Guillou (W)

Aerial radiological monitoring surveys, Fort Worth, Texas
J. A. Pitkin (W)

Aerial radiological monitoring surveys, Killeen, Texas
J. A. Pitkin (W)

Aerial radiological monitoring surveys, Gnome site, New Mexico
R. B. Guillou (W)

Aerial radiological monitoring surveys, Nevada Test Site
J. L. Meuschke (W)

Aerial radiological monitoring surveys, National Reactor Testing Station, Idaho
R. G. Bates (W)

Aerial radiological monitoring surveys, Los Angeles, California
R. B. Guillou (W)

Aerial radiological monitoring surveys, San Francisco, California
J. A. Pitkin (W)

Aerial radiological monitoring surveys, Hanford, Washington
R. G. Schmidt (W)

Aerial radiological monitoring surveys, Chariot site, Alaska
R. G. Bates (W)

Distribution of elements as related to health:

Airborne radioactivity and environmental studies, Washington County, Maryland
R. M. Moxham (W)

Magnetic susceptibility studies of cancerous tissues
F. E. Senftle (W)

Geochemistry of fluorine as related to its physiological effects
M. Fleischer (W)

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Paleontology:
  Systematic paleontology:
    Fossil wood and general paleobotany
      R. A. Scott (D)
    Paleozoic paleobotany
      S. H. Mamay (W)
    Coal lithology and paleobotany
      J. M. Schopf (Columbus, Ohio)
    Lower Pennsylvania floras of Illinois and adjacent States
      C. B. Read (Albuquerque, N. Mex.)
    Palynology
      G. O. W. Kremp (D)
    Post-Paleozoic pollen and spores
      E. B. Leopold (D)
    Charophytes and nonmarine ostracodes
      R. E. Peck (W)
    Diatom studies
      K. E. Lohman (W)
    Recent Foraminifera, Central America
      P. J. Smith (M)
    Cenozoic Foraminifera, Colorado Desert
      P. J. Smith (M)
    Foraminiferal studies of the Pacific Northwest
      W. W. Rau (M)
    Foraminifera of the Lodo formation, central California
      M. C. Israelsky (M)
    Cretaceous Foraminifera of the Nelchina area, Alaska
      H. R. Bergquist (W)
    Cretaceous Foraminifera, New York
      N. F. Sohl (W)
    Upper Paleozoic fusulines
      L. G. Henbest (W)
    Post Paleozoic larger Foraminifera
      R. C. Douglass (W)
    Lower Paleozoic corals
      W. A. Oliver, Jr. (W)
    Upper Paleozoic corals
      W. J. Sando (W)
    Bryozoans and corals, Western United States and Alaska
      H. Duncan (W)
    Cenozoic nonmarine mollusks
      D. W. Taylor (W)
    Cenozoic mollusks, Atlantic coast
      D. Wilson (W)
    Cenozoic mollusks, Atlantic and Gulf Coastal Plains
      D. Wilson (W)
    Cenozoic mollusks, Oregon, Miocene
      E. J. Trumbull (M)
    Cenozoic mollusks, Oregon, Oligocene
      E. J. Trumbull (M)
    Cenozoic mollusks, Alaska
      F. S. MacNeil (M)
    Cenozoic faunas, Caribbean area
      W. P. Woodring (W)
    Cenozoic invertebrates, Pacific Islands
      M. R. Todd (W)
    Cenozoic mollusks, Pacific Islands
      H. S. Ladd (W)
    Oligocene gastropods and pelecypods, Mississippi
      F. S. MacNeil (M)
    Oligocene gastropods and pelecypods, Pacific Islands
      F. S. MacNeil (M)

Paleontology—Continued
  Systematic paleontology—Continued
    Upper Paleozoic gastropods
      E. L. Yochelson (W)
    Ostracodes, Upper Paleozoic and younger
      I. G. Sohn (W)
    Lower Paleozoic ostracodes
      J. M. Berdan (W)
    Vertebrate paleontologic studies
      G. E. Lewis (D)
    Vertebrate faunas, Martha's Vineyard, Massachusetts
      F. C. Whitmore, Jr. (W)
    Vertebrate paleontology, Big Bone Lick, Kentucky
      F. C. Whitmore, Jr. (W)
    Vertebrate faunas, Ishigaki, Ryukyu Islands
      F. C. Whitmore, Jr. (W)
  Stratigraphic paleontology:
    Lower Paleozoic stratigraphic paleontology, Eastern United States
      R. B. Neuman (W)
    Cambrian faunas and stratigraphy
      A. R. Palmer (W)
    Ordovician stratigraphic paleontology of the Great Basin and Rocky Mountains
      R. J. Ross, Jr. (D)
    Silurian and Devonian stratigraphic paleontology of the Great Basin and Pacific Coast
      C. W. Merriam (W)
    Upper Paleozoic stratigraphic paleontology, Western United States and Alaska
      J. T. Dutro, Jr. (W)
    Permian stratigraphy, northeastern Arizona
      C. B. Read (Albuquerque, N. Mex.)
    Mesozoic stratigraphic paleontology, Atlantic and Gulf Coasts
      N. F. Sohl (W)
    Mesozoic stratigraphic paleontology northwestern Montana
      W. A. Cobban (D)
    Mesozoic stratigraphic paleontology, Pacific Coast
      D. L. Jones (M)
    Cordilleran Triassic stratigraphy
      N. J. Silberling (M)
    Jurassic stratigraphic paleontology of North America
      R. W. Imlay (W)
    Cretaceous stratigraphy and paleontology, western interior United States
      W. A. Cobban (D)
    Stratigraphic significance of the genus *Tempskya* in southwestern New Mexico
      C. B. Read (Albuquerque, N. Mex.)
    Paleontology and stratigraphy of the Pierre shale, Front Range, Colorado
      W. A. Cobban (D)
    Geology and paleontology of the Cuyama Valley area, California
      J. G. Vedder (M)
    Cenozoic stratigraphic paleontology
      D. Wilson (W)
    Ecologic studies on Onotoa Atoll
      P. E. Cloud (W)

Geomorphology and plant ecology:
    Sedimentation laboratory for flume experiments
      E. D. McKee (D)

Geomorphology and plant ecology—Continued
Pacific Islands vegetation
F. R. Fosberg (W)
*Potomac Basin studies, Maryland, Virginia, and West Virginia
J. T. Hack (W)
Physical properties of rocks:
Investigations of thermodynamic properties of ore and rock minerals
R. A. Robie (W)
Investigation of deformation, elasticity, and mineral equilibria of rocks
E. C. Robertson (W)
Investigation of elastic and anelastic properties of earth materials
L. Peselnick (W)
Investigations of electrical and thermal properties of rocks
G. V. Keller (D)
Measurement of magnetic properties of rocks
W. E. Huff (W)
Magnetic susceptibility of minerals
F. E. Senftle (W)
Infrared and ultraviolet radiation studies
R. M. Moxham (W)
Permafrost studies:
Arctic ice and permafrost studies, Alaska
A. H. Lachenbruch (M)
Thermistor studies
C. H. Sandberg (M)
Ground ice and permafrost, Point Barrow, Alaska
R. F. Black (Madison, Wis.)
*Surficial geology and permafrost of Johnson River district, Alaska
G. W. Holmes (W)
Origin and stratigraphy of ground ice in central Alaska
T. L. Péwé (College, Alaska)
Rock deformation:
Analysis of fault patterns
D. J. Varnes (D)
Diatremes, Navajo and Hopi Indian Reservations
E. M. Shoemaker (M)
Paleomagnetism:
Investigation of remanent magnetization of rocks
R. R. Doell (M)
Crustal studies:
Thermal studies (earth temperatures)
H. C. Spicer (W)
Volcanism and crustal deformation
L. C. Pakiser (D)
Gravity map of the United States
H. R. Joesting (W)
Cross-country aeromagnetic profiles
E. R. King (W)
Maine aeromagnetic surveys
J. W. Allingham (W)
Maine gravity studies
M. F. Kane (W)
Geophysical studies of Appalachian structure
E. R. King (W)
Central and Western North Carolina regional aeromagnetic survey
R. W. Johnson, Jr. (Knoxville, Tenn.)
Crustal studies—Continued
Aeromagnetic studies, Middlesboro-Morristown area, Tennessee-Kentucky-Virginia
R. W. Johnson, Jr. (Knoxville, Tenn.)
Aeromagnetic profiles over the Atlantic Continental Shelf and Slope
E. R. King (W)
Geophysical studies in the Rowe-Mora area, New Mexico
G. E. Andreasen (W)
Colorado Plateau regional geophysical studies
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D. R. Mabey (M)
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G. E. Andreasen (W)
Geophysical studies, airborne surveys, Alaska
G. E. Andreasen (W)
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Mineralogy and crystal chemistry:
Rock-forming silicate minerals
H. T. Evans (W)
Serpentine and related silicate minerals
H. T. Evans (W)
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H. T. Evans (W)
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Mineralogy and geochemistry of the Green River formation, Wyoming
C. Milton (W)
Mineralogic services and research, Denver
T. Botinelly (D)
Mineralogic services and research, Menlo Park
R. G. Coleman (M)
Mineralogic services and research, Washington, D.C.
A. D. Weeks (W)
Thin and polished sections
F. Reed (W)
Thin and polished sections
M. C. Cochran (D)
Thin and polished sections
R. G. Coleman (M)
Experimental geochemistry:
Solution chemistry of ore-fluids transport
E. W. Roedder (W)
Fluid inclusions in minerals
E. W. Roedder (W)
Application of phase equilibria to geologic thermometry
B. J. Skinner (W)
Experimental studies on rock alteration
J. Hemley (D)
Hydrothermal solubility
G. W. Morey (W)
Thermophysical properties of sulfides and silicates
B. J. Skinner (W)
Thermodynamic properties of sulfides and sulfosalts
E. W. Roedder (W)
Hydrothermal silicate and carbonate systems
B. J. Skinner (W)
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B. J. Skinner (W)

Experimental geochemistry—Continued
- Sulfide and sulfosalt systems
  - E. W. Roedder (W)
- The system $NaCl-K_2SO_4-MgSO_4-CaSO_4$
  - G. W. Morey (W)
- The system UO_3-H_2O
  - G. W. Morey (W)
- Mineral equilibria of rocks: system $MgO-Al_2O_3-SiO_2$
  - F. Barker (W)
- Evaporite mineral equilibria: liquidus relations in the system $NaCl-CaSO_4-H_2O$ at low temperature
  - E-an Zen (W)
- Geochemistry of borate minerals
  - H. T. Evans (W)

Geochemical distribution of the elements:
- Geochemical distribution of elements
  - M. Fleischer (W)
- Geochemical compilation of rock analysis
  - M. Hooker (W)
- Chemical analyses of sedimentary rocks
  - T. P. Hill (W)
- Trace element distribution among coexisting minerals
  - E. W. Roedder (W)
- Geochemistry of minor elements
  - E. S. Larsen, 3d (W)
- Uranium and thorium in magmatic differentiation
  - E. S. Larsen, 3d (W)

Organic geochemistry:
- Geochemistry of naturally occurring carbonaceous substances
  - F. S. Grimaldi (W)
- Special studies of isotope fractionation in living organisms
  - F. D. Sisler (W)

Petrology:
- Origin and characteristics of thermal and mineral waters
  - D. E. White (W)
- Sedimentary petrology and clay mineral studies
  - J. C. Hathaway (D)
- Studies of welded tuff
  - R. L. Smith (W)
- Metamorphism and origin of mineral deposits, Gouverneur area, New York
  - A. E. J. Engel (Pasadena, Calif.)
- Igneous rocks of southeastern United States
  - C. Milton (W)
- *Petrology of the Manassas quadrangle, Virginia
  - C. Milton (W)
- *Petrology of the Valles Mountains, New Mexico
  - R. L. Smith (W)
- Chemical and physical properties of the Pierre shale, Montana, North Dakota, South Dakota, Wyoming and Nebraska
  - H. A. Tourtelot (D)
- Geology and paleolimnology of the Green River formation, Wyoming
  - W. H. Bradley (W)
- *Petrology of the Bearpaw Mountains, Montana
  - W. T. Pecora (W)
- Carbonatite deposits, Montana
  - W. T. Pecora (W)
- *Petrology of the Wolf Creek area, Montana
  - R. G. Schmidt (W)

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- Chromite resources and petrology of the Stillwater ultramafic complex, Montana
  - E. D. Jackson (M)
- *Sedimentary petrology and geochemistry of the Belt series; Elmira, Mt. Pend Oreille, Packsaddle Mountains, and Clark Fork quadrangles, Idaho-Montana
  - J. E. Harrison (D)
- *Metamorphism of the Orofino area, Idaho
  - A. Hietanen-Makela (W)
- Petrology and geochemistry of the Boulder Creek batholith, Colorado Front Range
  - E. S. Larsen, 3d (W)
- Petrology and geochemistry of the Laramide intrusives in the Colorado Front Range
  - E. S. Larsen, 3d (W)
- Petrology of volcanic rocks, Snake River Valley, Idaho
  - H. A. Powers (D)
- Glaucophane schist terranes within the Franciscan formation, California
  - R. G. Coleman (M)
- *Petrology and volcanism, Katmai National Monument, Alaska
  - G. H. Curtis (M)
- Geological, geochemical, and geophysical studies of Hawaiian volcanology
  - K. J. Murata (Hawaii)
- Petrological services and research
  - C. Milton (W)

Isotope and nuclear studies:
- Isotope ratios in rocks and minerals
  - I. Friedman (W)
- Investigation of sea-level changes in New England
  - M. Rubin (W)
- Geochronology: carbon-14 method
  - M. Rubin (W)
- Geochronology: lead-uranium ages of mineral deposits
  - L. R. Stieff (W)
- Geochronology: lead-alpha ages of rocks
  - T. W. Stern (W)
- Significance of lead-alpha age variation in batholiths of the Colorado Front Range
  - E. S. Larsen, 3d (W)
- Geochronology: potassium-argon method
  - H. Faul (W)
- Age determinations: rocks in Colorado
  - H. Faul (W)
- Age determinations: granites of Maine
  - H. Faul (W)
- Nuclear irradiation
  - C. M. Bunker (D)
- Radioactive nuclides in minerals
  - F. E. Senftle (W)

Analytical chemistry:
- Rock and mineral chemical analysis
  - J. J. Fahey (W)
- General rock chemical analysis
  - L. C. Peck (D)
- Research on trace analysis methods
  - F. N. Ward (D)
- Trace analysis and research
  - J. H. McCarthy, Jr. (D)

Analytical chemistry—Continued
- Analytical services and research, Washington, D.C.
  - F. S. Grimaldi (W)
- Analytical services and research, Denver
  - L. F. Rader, Jr. (D)
- Analytical services and research, Menlo Park
  - R. E. Stevens (M)
- Rapid rock chemical analysis
  - W. W. Brannock (W)
- Petroleum geology laboratory
  - H. A. Tourtelot (D)

Spectroscopy:
- X-ray spectroscopy of ore minerals
  - I. Adler (W)

Spectroscopy—Continued
- Spectrographic services and research, Washington, D.C.
  - A. W. Helz (W)
- Spectrographic services and research, Denver
  - A. T. Myers (D)

General bibliographies and handbooks:
- Bibliography of North American geology
  - M. Cooper (W)
- Geophysical abstracts
  - J. W. Clarke (W)
- Geochemical exploration abstracts and information
  - H. W. Lakin (D)
- Statistics handbook
  - T. G. Lovering (D)

GEOLOGIC DIVISION PUBLICATIONS IN FISCAL YEAR 1960

Listed below are the citations of the Geologic Division's technical reports published or otherwise released to the public during fiscal year 1960. The list does not include all publications that bear dates between July 1959 and June 1960 because publication of periodicals is sometimes delayed for several months. Neither does the list include a full year's publications for journal articles bearing dates prior to July 1959 have not been included, even though they may have been actually released during the fiscal year.

The reports are listed alphabetically by author in the bibliography. In addition, a subject classification of the reports is given on pages A127–A136. The topics listed there are those discussed in the main section of the previous part of this report, and they are arranged in the same way.

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- Denson, 1959

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- King, R. R., Jussen, Loud, and Conant, 1960
- King, R. R., and others, 1959
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- Soister and Conklin, 1959
- Warner, Holser, Wilmarth, and Cameron, 1959
- Weld, Asselstine, and Johnson, 1959, 1960
- Wilson, Druid, 1959
- Withington and Jaster, 1960

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- Balsley and Buddington, 1960
- Balsley, Buddington, and others, 1959a–c
- Balsley, Postel, and others, 1959
- Boucot and Arndt, 1960
- Boucot, Griscom, Allingham, and Dempsey, 1960
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- Castle, 1959
- Engel, A. E. J., and Engel, C. G., 1960
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- Leonard and Vlisidis, 1960
- Luedke, Wrucke, and Graham, 1959
- Postel, Nelson, and Wiesnet, 1959
- Smysor, 1959a
- Toulmin, 1959

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- Amos, 1959
- Arndt, Conlin, Kuhn, Miller, and Wood, 1959
- Bell, 1959
- Bromery, 1959
- Bromery, Bennett, and others, 1959a–c
- Bromery, Henderson, and Bennett, 1959
- Bromery, Henderson, Zandle, and others, 1959a, b; 1960a–l
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- Bryant and Reed, 1959
- Cattermole, 1960
- Friedman, J. D., 1959b
- Glover, 1959
- Griscom, 1959
- Hack, 1960
- Hack and Young, 1959
- Johnson, R. W., Jr., 1959
- King, E. R., and Zietz, 1960
- Laurence, 1960
- Lesure, 1959
- Luedke, Wrucke, and Graham, 1959
- Murphy, 1960
- Neuman, 1960
- Overstreet, Theobald, and Whitlow, 1959
- Sando, 1960
- Smith, W. L., Stone, Ross, and Levine, 1960
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- Stern, Stieff, Klemic, and Delevaux, 1959
- Stromquist and Conley, 1959
- Wilpolt and Marden, 1960
- Wood, Arndt, and Kehn, 1959
- Zietz and Gray, 1959

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- Brown, 1959
- Carr, W. J., and Alverson, 1959
- Carroll, 1959a, b

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- Cathcart and McGreevy, 1959
- Cooke, 1959
- Johnston, Trumbull, and Eaton, 1959
- Ketner, 1959
- King, E. R., 1959a
- King, E. R., Zietz, and Dempsey, 1960
- Knechtel, Hosterman, and Hamlin, 1959
- Malde, 1959a
- Minard, 1960
- Murphy, 1960
- Owens and Minard, 1960
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- Colton, G. W., and de Witt, 1959
- de Witt and Colton, G. W., 1959a, b
- Droste, Rubin, and White, G. W., 1959
- Faul and Thomas, 1959
- Friedman, J. D., 1959b
- Glover, 1959
- Hass, 1959
- King, E. R., and Zietz, 1960
- Luedke, Wrucke, and Graham, 1959
- Marcher, 1959
- Oliver, 1960
- Patterson and Hosterman, 1960
- Wilpolt and Marden, 1960

Shield area and upper Mississippi Valley:
- Bayley, 1959a, c
- Behre and Heyl, 1959
- Gill, Schultz, and Tourtelot, 1960
- Heyl, Agnew, Lyons, and Behre, 1960
- Heyl, Milton, and Axelrod, 1959
- James, 1960
- James, Dutton, Pettijohn, and Wier, 1960
- Kepferle, 1959
- Kottlowski, 1960a, b
- Mudge, Walters, and Skoog, 1959
- Stoiber, and Davidson, 1959
- Warrick and Winslow, 1960
- White, W. S., 1960a, b

Gulf Coastal Plain and Mississippi Embayment:
- Eargle, 1959a–c; 1960a
- Evans and McKnight, 1959a, b
- Weeks and Eargle, 1959
- Welch, 1960

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- Adkison, 1960
- Baltz, 1960
- Burnside, 1959
- Byerly, Stewart, and Roller, 1960
- Chisholm, 1959
- Cloud and Palmer, 1959
- Dane, 1959
- Eargle, 1960b
- Frezon and Glick, 1959
- Hale and Clebsch, 1959
- Hamilton, 1959
- Hayes, 1959
- Jackson and Warrick, 1959
- Jones, C. L., 1959, 1960

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- Jones, C. L., and Madsen, 1959
- Landis, 1960
- Mamay, 1959
- Moore, 1959a, b
- Motts, 1959
- Mudge and Burton, 1959
- Roller, Stewart, Jackson, Warrick, and Byerly, 1959
- Stafford, 1959
- Terriere, 1960
- Vine, 1960
- Yates and Thompson, 1960

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- Arnold, Coleman, and Fryklund, 1959
- Baker, 1959
- Bayley, 1959b
- Bowles and Braddock, 1960
- Calkins, Parker, and Disbrow, 1959
- Campbell, 1959
- Cheney and Sheldon, 1959
- Cobban, Erdmann, Lemke, and Maughan, 1959a, b
- Colton, R. B., 1959
- Crittenden, 1959
- Denson, Bachman, and Zeller, 1959
- Fraser, 1960
- Gardner, 1959
- Gildersleeve, 1959
- Gill, 1959
- Gill, Schultz, and Tourtelot, 1960
- Gill, Zeller, and Schopf, 1959
- Gott, Braddock, and Post, 1960
- Hadley, 1959a, b
- Hallgarth, 1960
- Izett, Mapel, and Pillmore, 1960
- Johnson, W. D., Jr., and Kunkel, 1959
- Jones, W. R., Peoples, and Howland, 1960
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- Klepper and Smedes, 1959
- Landis, 1960
- Leo, 1960
- Love, 1959, 1960
- Love and Milton, 1959
- McKelvey and others, 1959
- Mapel and Gott, 1959
- Marshall, 1960a–c
- Masursky and Pipiringos, 1959
- Milton, Chao, Axelrod, and Grimaldi, 1960
- Milton and Eugster, 1959
- Milton and Fahey, 1960
- Milton, Mrose, Chao, and Fahey, 1959
- Moore, Melin, and Kepferle, 1959
- Mudge, 1959
- Mudge and Dobrovolny, 1959
- Muessig and Quinlan, 1959
- Myers, 1960
- Nelson, 1959
- Olson, 1960
- Post, 1959
- Redden, 1959
- Robinson, C. S., 1960
- Robinson, G. D., 1959a, b
- Ross, C. P., 1960
- Ross, C. P., and Rezak, 1959
- Ross, R. J., Jr., 1959

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- Sandberg, C. A., 1960
- Sandberg, D. T., 1959
- Sando, Dutro, and Gere, 1959
- Schultz, Tourtelot, and Gill, 1960
- Sheldon, 1959a, b
- Smith, J. F., Jr., Witkind, and Trimble, 1960
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- Vine, 1959a, 1959b
- Vine and Prichard, 1960
- Waage, 1959a
- Weis, 1959
- Witkind, 1959
- Wolcott and Gott, 1960
- Zeller and Schopf, 1959

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- Bailey, R. A., 1959
- Christman, Brock, Pearson, and Singewald, 1960
- Dane, 1959
- Donnell, 1959
- Gildersleeve, 1959
- Gill, Schultz, and Tourtelot, 1960
- Harbour and Dixon, 1959
- Johnson, R. B., 1960
- King, E. R., 1959b
- Kinney and Hail, 1959
- Landis, 1959, 1960
- Pearson, 1959
- Ratté and Steven, 1959
- Scott, G. R., and Cobban, 1959
- Sims, Moench, and Harrison, 1959
- Steven and Ratté, 1959
- Tweto, 1959
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- Waage, 1959b
- Wilmarth, 1959

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- Archbold, 1959
- Bachman, Vine, Read, and Moore, 1959
- Botinelly and Fischer, 1959
- Bush, Marsh, and Taylor, 1959
- Byerly and Joesting, 1959
- Cadigan, 1959a, b
- Cannon, H. L., 1959
- Cashion, 1959
- Craig, Holmes, Freeman, Mullens, and others, 1959
- Dane, 1959, 1960
- Ekren and Houser, 1959a–c
- Elston and Botinelly, 1959
- Engel, C. G., 1959
- Finch, 1959b
- Fischer, R. P., 1959
- Fisher, Erdmann, and Reeside, 1960
- Foster, 1959a
- Garrels and Christ, 1959
- Garrels and Larsen, 1959
- Garrels, Larsen, Pommer, and Coleman, 1959
- Hemphill, 1959
- Hilpert and Moench, 1960
- Houser and Ekren, 1959a, b
- Johnson, H. S., Jr., 1959a, b
- Keller, G. V., 1959a, b
- Keller, W. D., 1959

Colorado Plateau—Continued
- Kinney, Hansen, and Good, 1959
- Krieger, 1959
- Landis, 1959
- Lewis, R. Q., and Trimble, 1960
- Marshall, 1959
- Newman and Elston, 1959
- Petersen, 1959, 1960
- Petersen, Hamilton, and Myers, 1959
- Petersen and Phoenix, 1959
- Phoenix, 1959
- Repenning, 1959
- Roach and Thompson, 1959
- Schlee, 1959
- Schlee and Moench, 1960
- Shoemaker, 1959a, b
- Shoemaker, Miesch, Newman, and Riley, 1959
- Shoemaker and Newman, 1959
- Stern and Stieff, 1959
- Stewart, 1959
- Stewart, Williams, Albee, and Raup, 1959
- Trites, Chew, and Lovering, 1959
- Truesdell and Weeks, 1959
- Wanek, 1959
- Weeks, Coleman, and Thompson, 1959
- Weeks and Garrels, 1959
- Wells, 1959

Basin and Range province:
- Anderson, C. A., 1959
- Christ and Garrels, 1959
- Clebsch and others, 1959
- Cooper, 1959a, b; 1960
- Cornwall and Kleinhampl, 1959
- Dane, 1959
- Dibblee, 1959a–c; 1960a–d
- Dickey and McKeown, 1960
- Diment, Healey, and Roller, 1959
- Diment and others, 1959a–d
- Drewes, 1959
- Erd, McAllister, and Almond, 1959
- Gibbons, 1960
- Gibbons, Hinrichs, Hansen, and Lemke, 1960
- Gilluly, 1960
- Hall, W. E., 1959
- Hose and Repenning, 1959
- Houser and Poole, 1959a, b; 1960
- Keller, G. V., and others, 1959
- Longwell, 1960
- Lovering and others, 1960
- Lovering and Shepard, 1960
- Mabey, 1960
- Mabey and others, 1959
- McClymonds, 1959
- McKelvey and others, 1959
- McKeown and others, 1959
- McKeown and Wilmarth, 1959
- Mapel and Hail, 1959
- Neuerburg and Granger, 1960
- Olson and Hinrichs, 1960
- Outerbridge, Staatz, Meyrowitz, and Pommer, 1960
- Palmer, 1960a, c
- Peterson, 1959
- Pomeroy, 1959
- Poole and Roller, 1960

Basin and Range province—Continued
- Price, 1960
- Ross, C. P., 1960
- Silberling, 1960
- Smith, G. I., 1959
- Staatz and Osterwald, 1959
- Tatlock, Wallace, and Silberling, 1960
- Tschanz, 1959
- Tschanz and Pampeyan, 1960
- Wallace, Silberling, Irwin, and Tatlock, 1959
- Wallace, Silberling, and Tatlock, 1960
- White, D. E., and Craig, 1959
- Wilmarth, 1960
- Wilmarth and others, 1959
- Wilson, R. F., and Stewart, 1959

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- Baldwin and Hill, 1960
- Kinoshita and Kent, 1960
- McKelvey and others, 1959
- Malde, 1959b
- Mapel and Hail, 1959
- Pakiser, 1960b
- Ross, C. P., 1960
- Vhay, 1960

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- Bailey, E. H., 1960
- Bailey, E. H., Christ, Fahey, and Hildebrand, 1959
- Bailey, E. H., and Irwin, 1959
- Balsley, Bromery, Remington, and others, 1960
- Beikman and Gower, 1959
- Bonilla, 1959, 1960
- Bromery, Emery, and Balsley, 1960
- Brown, Gower, and Snavely, 1960
- Clark, L. D., 1960
- Coleman, 1959b
- Crandell and Gard, 1959
- Crowder, 1959
- Durham and Jones, 1959
- Hall, C. A., Jones, D. L., and Brooks, 1959
- Imlay, Dole, Wells, and Peck, 1959
- Jones, D. L., 1959a, 1960a, b
- Kinoshita and Kent, 1960
- McGill, 1959
- Mallory, 1959
- Pakiser, 1960a, b
- Pakiser, Press, and Kane, 1960
- Peck, D. L., 1960
- Radbruch, 1959
- Rinehart, 1959
- Rinehart, Ross, and Huber, 1959
- Smith, P. B., 1960

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- Barnes, D. F., 1959
- Barnes, F. F., and Cobb, 1959
- Benninghoff and Holmes, 1960
- Berg and MacKevett, 1959
- Berquist, 1960
- Byers, 1960
- Carr, M. S., and Dutton, 1959
- Cass, 1959a–f
- Coats, 1959
- Cobb, 1959a–d
- Dutro, 1960a, b

Alaska—Continued
- Eckhart and Plafker, 1959
- Fellows and others, 1959
- Fernald, 1959
- Fraser and Snyder, 1960
- Gates, G. O., 1959
- Grantz, 1960a–c
- Gryc, 1959, 1960
- Hoare and Coonrad, 1960a, b
- Holmes, G. W., 1959a–d
- Holmes, G. W., and Lewis, C. R., 1960
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- Hopkins and Benninghoff, 1960
- Hummel, 1960
- Kachadoorian, 1960
- Kachadoorian, Campbell, Sainsbury, and Scholl, 1959
- Kachadoorian and others, 1960
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- Karlstrom, 1960
- Karlstrom and others, 1959
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- Keller, G. V., and Frischknecht, 1960
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- Lachenbruch and Brewer, 1959
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- Lathram, Loney, Condon, and Berg, 1959
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- MacKevett, 1959a, b
- Miller, D. J., 1960a, b
- Miller, D. J., MacNeil, and Wahrhaftig, 1960
- Miller, D. J., Payne, and Gryc, 1959
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- Péwé, Hopkins, and Lachenbruch, 1959
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