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GEOLOGICAL SURVEY RESEARCH 1964

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 501–A

GEOLOGICAL SURVEY RESEARCH 1964

THOMAS B. NOLAN, *Director*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 501

Significant results of investigations for fiscal year 1964, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as Chapters A, B, C, and D

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, Secretary

GEOLOGICAL SURVEY

Thomas B. Nolan, Director

GEOLOGICAL SURVEY RESEARCH 1964

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 501–A

A summary of recent significant scientific and economic results, accompanied by a list of publications released in fiscal 1964, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1964

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FOREWORD

Geological Survey Research 1964 is the fifth annual review of the economic and scientific work of the U.S. Geological Survey. As in previous years the purpose of the volume is to make available promptly to the public the highlights of Survey investigations. This year the volume consists of 4 chapters (A through D) of Professional Paper 501. Chapter A contains a summary of significant results, and the remaining chapters are made up of collections of short technical papers.

Many of the results summarized in chapter A are discussed in greater detail in the short papers or in reports listed in "Publications in Fiscal Year 1964," beginning on page A277. The tables of contents for chapters B through D are listed on pages A271–A275. Next year, the sixth year of publication of this series, Geological Survey Research 1965 will appear as chapters of Professional Paper 525.

Numerous Federal, State, county, and municipal agencies listed on pages A221–A225 cooperated financially with the Geological Survey during fiscal 1964 and have contributed significantly to the results reported here. They are identified where appropriate in the short technical papers, but generally are not identified in the brief statements in chapter A.

Many individuals on the staff of the Geological Survey have contributed to Geological Survey Research 1964. Reference is made to only a few. George H. Davis was responsible for organizing and assembling chapter A and for critical review of papers in chapters B–D. He was assisted by George Phair, who was largely responsible for material from the Geologic Division. Marston S. Chase was in charge of production aspects of the series, assisted by Jesse R. Upperco in technical editing, and William H. Elliott in the planning and preparation of illustrations.

Thomas B. Nolan

THOMAS B. NOLAN,
Director.

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ILLUSTRATIONS

INVESTIGATIONS OF NATURAL RESOURCES

The Act of Congress that created the U.S. Geological Survey in 1879 charged its Director with the "classification of the public lands," and with the "examination of the geological structure, mineral resources and products of the national domain." Over the years the Survey's program has evolved to meet the Nation's changing needs, but the objectives spelled out in the organic act remain its cardinal guidelines. This volume, the fifth in the series of annual summaries, presents the more significant results of the many separate investigations underway in 1964. A broad outline of the Survey's future plans, entitled "Long Range Plan For Resource Surveys, Investigations, and Research Programs of the United States Geological Survey," was published during the present calendar year and is available without charge from the Geological Survey, Washington, D.C. 20242.

MINERAL RESOURCES

Growth in population and rise in level of living are steadily accelerating our consumption of minerals, fuels, and water, and are creating enormous future demands for these key resources. This problem is highlighted as a part of the "Challenge to Greatness" theme carried by the Federal Pavilion at the New York World's Fair in an exhibit, reproduced in figure 1. The exhibit makes the points that minerals, fuels, and water are the essence of our industrial society; that increased per capita consumption of them is the physical basis for rise in level of living; that the needs of the present population are far larger than known supplies; and, most important, that future needs can be met provided we undertake the driving and imaginative research necessary to find and develop new supplies. This means acquiring better prospecting tools and methods, better knowledge of the origin, habits, and distribution of mineral deposits, better understanding of the three-dimensional geology of our real estate, and better knowledge of the extent and distribution of minerals that are presently too costly to use but that may come within economic reach as technology advances.

Results of Survey investigations that bear directly on mineral-resource studies are summarized in the following pages. Nearly all the Survey's investigations help advance knowledge in these areas, but only those results that are directly concerned with mineral resources are described in this section.

RESOURCE COMPILATION

Resources of Utah, Alaska, and South Dakota

Current knowledge of the economic mineral and water resources of Utah, Alaska, and South Dakota has been summarized in three reports prepared jointly by the Geological Survey and State agencies. In addition to describing known mineral deposits, the reports synthesize much recent work bearing on areas favorable for further prospecting. For example, in Utah (U.S. Geological Survey, 9–64),[1] three beltlike areas contain most of the known hydrothermal deposits in the State from which all of the molybdenum, mercury, and halloysite, and 95 percent of the copper, lead, silver, gold, and zinc have been produced, as well as most of the manganese, tungsten, barite, fluorite, native sulfur, minor metals, and significant amounts of uranium, alunite, and gem materials. In addition, major potential resources of beryllium have been identified. (See also "Water Resources, . . . Utah.") In Alaska (U.S. Geological Survey, 8–64), geologic structures are compared with the Cascade-Sierra cordillera, the Columbia and Colorado Plateaus, and the Rocky Mountains of the western conterminous States to point out the similarities in mineral resources and to suggest favorable areas for exploration. (See also "Water Resources, . . . Alaska".)

In South Dakota [2] the distribution of pegmatites in the Black Hills is spatially related to the Harney Peak Granite, but of approximately 20,000 pegmatites only 200 are of the zoned type that have been mined for different minerals. Of these minable pegmatites, those worked for sheet mica tend to be near the granite, while those worked for scrap mica, beryl, and lithium

[1] See "List of Publications" (p. A277). This report is the 9th citation for 1964 under entries for the U.S. Geological Survey and is listed on p. A324.

[2] U.S. Geological Survey, 1964, Mineral and water resources of South Dakota: U.S. Cong., 88th, 2d sess., U.S. Senate Comm. on Interior and Insular Affairs Rept. [In press]

minerals tend to be farther from the granite, toward the margin of the pegmatite area. Favorable environments for metallic mineral deposits occur in the vicinity of Tertiary intrusive masses elsewhere in the Black Hills. (See also "Water Resources, . . . South Dakota.")

Mineral potential of the northern Cascade Mountains, Wash.

Deposits of gold and copper, and of lead, zinc, and silver in the nothern Cascade Mountains of Washington are much more closely related spatially to granitic rocks of late Tertiary age than to older granites, according to a study by A. E. Weissenborn and F. W. Cater for the North Cascades Study Team, representing the U.S. Departments of Agriculture and Interior and the State of Washington. Ultramafic rocks in and near the Twin Sisters Mountains are an important source of olivine and contain small deposits of chromite. Weathering of the ultramafic rocks before and during early Tertiary time formed residual deposits of nickeliferous iron ore containing a little cobalt. The area is favorable for both copper and gold deposits, although the chances of finding a large mining district seem poor. The likelihood of discovery of new gold deposits would be good under more favorable economic conditions, and the byproduct output of gold should be expected from any new copper mines.

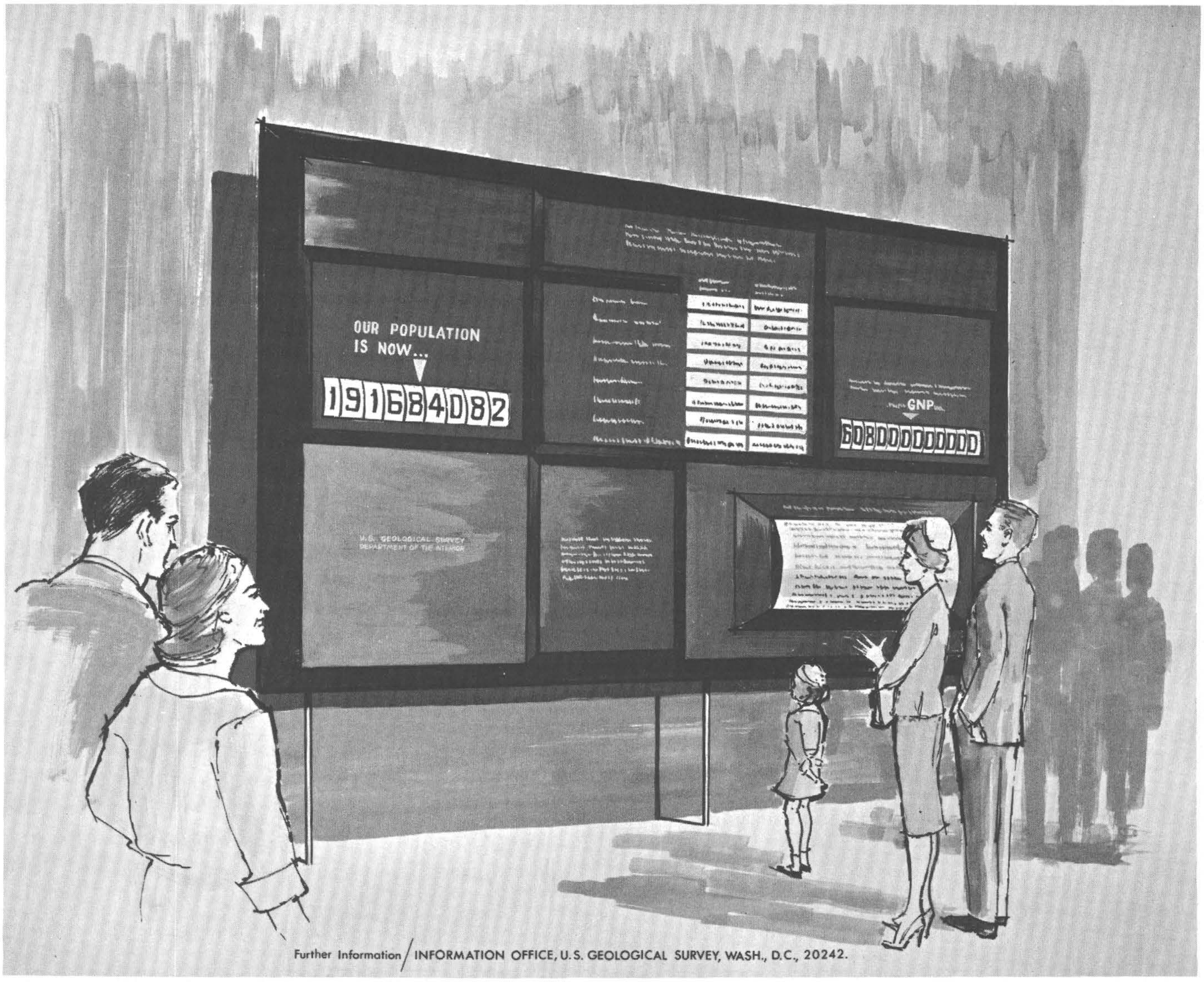

FIGURE 1.—Sketch of the exhibit on mineral resources and the Nation's growth being shown in the Federal Pavilion at the New York World's Fair as a part of its "Challenge to Greatness" theme. The exhibit provides a continuous tally of the Nation's population and its consumption of key commodities, and shows on the one hand how growth in population and per capita consumption increase the demand for minerals, and on the other, how mineral consumption supports economic growth.

HEAVY METALS

IRON

Marquette district, Michigan

Working from geologic maps prepared by the Cleveland Cliffs Iron Co., J. E. Gair has studied the hard iron ores in the Cliffs Shaft mine at Ishpeming. He finds that concentrations of magnetite commonly occur adjacent to mafic intrusive rock, now altered to greenstone, in nominally hematitic ores, and in both hematitic and sideritic iron-formation. Minor veinlets of sulfides in iron-formation and ore also occur most commonly near contacts of altered mafic intrusive bodies.

Cuyuna North Range, Minnesota

In a comprehensive report on the iron and manganiferous iron ores of the Cuyuna North Range, R. G. Schmidt (1–63) attributes the enrichment of the original iron-formation to two ore-forming stages. During the first stage, ground water heated by the admixture of magmatic emanations produced red-brown largely hematitic ore bodies, enriched in boron, that are spatially related to fracture zones and intrusions. All the largest deposits in the district include or consist entirely of ore of this type. The second stage of enrichment occurred during a period of very deep weathering when brown, largely goethitic ores formed as irregular blankets over exposures of iron-formation and on almost all the residual masses of unoxidized iron-formation that remained within the hematitic deposits. Porous hematitic ores that extended downward for several hundred feet served as channelways for the weathering solutions, so that brown ore formed to considerable depths. Some of the large ore bodies originated in this two-stage manner.

Magnetic anomaly in southeastern Minnesota

Isidore Zietz (1–64) found by aeromagnetic methods a high-amplitude anomaly in southeastern Minnesota that from its shape and size suggested the presence of Precambrian iron-formation in the basement, here overlain by flat-lying lower Paleozoic sedimentary rocks estimated to be 500 to 1,000 feet thick. Subsequently the New Jersey Zinc Co. revealed (written communication) that it had previously discovered this anomaly in 1961, and that a drill hole had entered diabasic-textured gabbroic rock containing concentrations of iron and titanium oxides at a depth of 724 feet.

MOLYBDENUM

White River Badlands, S. Dak.

R. U. King has studied molybdenum deposits of a previously unknown type found recently in the White River Badlands of South Dakota. A yellow molybdenum oxide, probably ferrimolybdite, cements lenses of sandstone, conglomerate, and claystone in the basal unit of the Chadron Formation, of Oligocene age, just above its contact with the underlying Pierre Shale. Individual deposits are as much as 100 feet long and 8 feet thick in outcrop; insufficient exploration has been done to delimit the third dimension. A small part of the material contains several percent of molybdenum, but the average grade is probably only a few tenths of 1 percent.

CHROMIUM

Stratiform and podiform chromite deposits contrasted

E. D. Jackson and T. P. Thayer conclude that (1) sedimentary principles govern occurrences of the stratiform chromite deposits such as those in the Stillwater complex, Montana, and (2) metamorphic principles apply to the podiform deposits associated with alpine-type peridotites as, for example, along the Pacific coast of the United States. Field examination by Jackson and Thayer of the Vourinos complex in Greece during the Seminar of Chromite Prospecting sponsored by the Organization for Economic Cooperation and Development and held in Athens in 1963 showed that this igneous body, considered to be a typical ophiolite flow, has many features of alpine complexes as described by Thayer (2–63) together with podiform chromite deposits. Similarly, examination of chromite deposits in the Hindubagh district of Pakistan by Roger van Vloten and T. W. Offield, in three important districts of Turkey by Thayer, and in the Philippines by D. L. Rossman shows that layering, foliation, and lineation have been generally neglected and misunderstood as possible guides in exploration and mining of podiform deposits. Relict structures, mostly in chromite, show that the peridotite and gabbro in alpine complexes formed by fractional crystallization as in the stratiform complexes, and that the flowage features were imposed during reemplacement as crystal mushes.

COPPER

Arizona

Alteration associated with copper deposits in Arizona was investigated with a truck-mounted gamma-ray spectrometer by R. M. Moxham, C. A. Anderson, and C. M. Bunker, of the Geological Survey, in cooperation with R. S. Foote, of Texas Instruments, Inc. Earlier work by Anderson and coworkers showed that potassium was added to the host rocks by hydrothermal alteration at the porphyry copper deposit at Bagdad and the massive sulfides at the Jerome, Iron King, and Old Dick mines. The present studies show that the potassic alteration extends a substantial distance from the locus of mineralization and can be detected by the spectrometric method. At the Bagdad deposit an abnormal amount of uranium (as much as 65 parts per million) is associated with the mineralized zone. As a check on the method, the field measurements were compared with results of chemical analyses for one or more of the radioactive elements, K, U, Th, obtained on over 50 samples collected at the outcrops.

Chewelah No. 1 quadrangle, Stevens County, Wash.

A moderately dipping thrust fault with several miles of displacement is an important structural feature in the Chewelah No. 1 quadrangle, Stevens County. Studies by L. D. Clark and F. K. Miller have indicated that the upper plate of the thrust, composed largely of Precambrian argillite and quartzite, possibly acted as a low-permeability cover or "lid" that aided in concentrating copper deposits in the rocks of the lower plate. If so, exploration of the lower plate rocks beneath weakly mineralized areas of the upper plate might be warranted. To date, copper has been produced only from an area where the upper plate rocks have been removed by erosion.

Springfield mine, Yellow Pine quadrangle, Idaho

A new interpretation of the structure of the bedrock ore body below minable colluvium at the Springfield mine in Valley County has economic implications. This scheelite-pyrrhotite deposit, originally described and mapped by H. B. Nickelson (unpublished data), is a high-temperature replacement of garnet-pyroxene skarn developed from carbonate rocks included within the alaskatic facies of the Idaho batholith near the Little Pestol dike swarm. Recent studies of B. F. Leonard suggest that the deposit may be a warped lathlike shoot on the crest of a small anticline trending about N. 5° E. and plunging 30°–35° NNE. In other terranes, some ore bodies on the noses of plunging folds extend to considerable depths. The metasedimentary rocks in the area are involved in three systems of folds; exposures are poor in the vicinity of the ore body. Previous drilling of the bedrock for tungsten had proved disappointing partly because its structure had been difficult to decipher. If the tungsten and copper content of this deposit should be of interest, the new hypothesis concerning the shape and structural localization of the mineralized body might be tested by geophysical surveys.

LEAD AND ZINC

Thompson-Temperly mine, southwest Wisconsin

Qualitative X-ray fluorescence analyses of selected samples of the basal shale of the Quimbys Mill Member of the Ordovician Platteville Formation show marked changes in the amounts of potassium, calcium, aluminum, silicon, magnesium, iron, manganese, and titanium outward from the ore body through the altered wall-rock halo into the unaltered shale. According to A. V. Heyl, all these elements except calcium are abundant in the ore body, and diminish to a minimum in the outer part of the alteration halo. Calcium, however, shows an inverse relationship.

Mount Wilson quadrangle, San Miguel and Dolores Counties, Colo.

C. S. Broomfield (1–63) has concluded that veins of base and precious metal ores are spatially, and probably genetically, related to the belt of intrusive rocks that extend westerly across the northern half of the quadrangle. The veins themselves seem in turn to be restricted within the intrustive belt to an east-west zone, no more than a mile or two in width, that crosses the quadrangle from the Ames-Matterhorn area on the east to the Silver Pick-Navajo Basin area on the west. The elongate vein zone closely approximates an imaginary axis that joins the centers of the major igneous masses. Most of the productive veins are along steep fissures that nearly parallel the postulated ore belt. A less prominent northeast system of veins and fissures has been prospected, but only one such vein has yielded substantial production. Northwest-trending joints or fissures are prominent, but have not been found to contain commercial ore shoots.

Santa Rita quadrangle, Grant County, N. Mex.

Soil samples collected above epidotized mafic dikes of pre-ore age exposed along the crest of Hermosa Mountain in Grant County contain anomalous amounts of zinc. The zinc anomaly appears to be at or near the center of a conspicuous magnetic anomaly recently mapped by W. R. Jones, J. E. Case, and W. P. Pratt (1–64) and may be worthy of further study.

TIN

Lost River mine, Alaska

Numerous data on the Lost River mine area collected by the Geological Survey, the Bureau of Mines, and the U.S. Tin Corp. with the financial assistance of the Defense Production Administration and Defense Minerals Exploration Administration have been assembled and evaluated by C. L. Sainsbury (1–64). Deposits of this area constitute the largest known U.S. tin resource and contain appreciable quantities of tungsten. Mineralization is associated with granite that intruded and marmarized limestone; the best ore is in a rhyolite porphyry dike that has been extensively greisenized and kaolinized. The surrounding area contains potentially valuable beryllium deposits.

Black Mountain, Seward Peninsula, Alaska

Reconnaissance of the biotite-granite pluton at Black Mountain, western Seward Peninsula, by C. L. Sainsbury has disclosed that the granite locally contains cassiterite and wolframite in quartz-topaz veinlets similar to those in the other tin-bearing granites of the general area. Neither tin nor tungsten had been found previously at Black Mountain. Although the known veinlets are small, cassiterite placers may exist in the streams flowing south from the granite pluton. Black Mountain apparently was not glaciated heavily during the Pleistocene, and placer deposits would not have been destroyed by glaciation as were those formed near the richer tin lodes of the Lost River area.

MANGANESE

Aguila mining district, Maricopa and Yuma Counties, Ariz.

A brief reconnaissance of the Aguila mining district by F. S. Simons has shown that most of the manganese oxide deposits, the principal ore of the district, are in intermediate to silicic volcanic rocks of presumed Tertiary age, and none is very far from outcrops of such rocks. Deposits of copper and lead, all apparently small, are mainly in Precambrian metamorphic rocks; a few copper prospects are in granitoid rocks that may be younger than Precambrian, and one lead deposit is in volcanic rocks. Gold deposits appear to be confined to Precambrian terrane. These observations suggest that ore deposits of 2 and possibly 3 ages are present: Tertiary (Mn, some Pb), Precambrian (Au, Cu, some Pb?), and possibly an intermediate age (Laramide?) (some Cu?). Furthermore, the close spatial association of deposits of manganese oxides with volcanic rocks strongly suggests a genetic relation. Finally, such widely different ages of mineralization indicate that no simple zonal relations exist among deposits of the various metals.

TUNGSTEN

Hamme tungsten district, North Carolina and Virginia

The geologic setting of the Hamme tungsten mine in Vance County, N.C., which is by far the largest deposit of this metal known in the Eastern United States, is described in a recent publication by J. M. Parker, 3d (1–63). Quartz-huebnerite veins containing minor quantities of fluorite and a few metallic sulfide minerals cut phyllite and albite granodiorite along a narrow belt 7½ miles long near the western contact of the granodiorite mass. The metasedimentary rocks of the district, derived mainly from graywackes and volcanic flows and subordinately from pyroclastic materials, are part of the Carolina slate belt and lie along the east edge of the Virgilina synclinorium. They, together with the albite granodiorite, are considered as probably of Paleozoic age; the latter may have formed by metasomatic replacement rather than intrusion of magma.

MERCURY

Red Devil mine, central Kuskokwim region, Alaska

E. M. MacKevett, Jr., and H. C. Berg (3–63) show by detailed maps and a block diagram the geologic setting and ore controls of the Red Devil quicksilver mine, in the central Kuskokwim region about 250 miles northwest of Anchorage. This mine was Alaska's largest mercury producer until it shut down recently. Northeastward-trending altered basic dikes of Tertiary age in Cretaceous graywacke and argillite have been cut by numerous northwestward-trending faults; the dike-fault intersections localized the deposition of cinnabar, stibnite, and other minerals from hydrothermal solutions in later Tertiary time. Although individual deposits are not large, numerous ore shoots, some of exceptionally high grade, have been found in an area at least 600 feet wide, 1,500 feet long, and 600 feet deep.

LABORATORY STUDIES OF SULFIDE ORE MINERALS

The sphalerite geothermometer

Paul Barton and Priestly Toulmin (1–64) have investigated the system Fe-Zn-S above 580°C and found that the widely used sphalerite geothermometer requires modification. The iron content of sphalerite in the common assemblage, sphalerite-pyrite, depends on the fugacity of sulfur, and can only be used as a geothermometer when an independent measure of F_{S_2} is available. Kullerud's[3] solvus curve for the binary system system FeS-ZnS is considerably in error.

Effect of sulfur upon the inversion temperature of chalcocite

In a continuing study of the system Cu-S, E. H. Roseboom has demonstrated by means of X-ray diffraction studies at high temperature that the inversion temperature of 104±1° C of low-temperature orthorhombic chalcocite (Cu_2S) to the high-temperature hexagonal polymorph is lowered to 93±2°C by the addition of 0.1 weight percent sulfur. The univariant reaction at 93°C with rising temperature is

$$\text{orthorhombic chalcocite} + \text{digenite} \leftrightarrows \text{hexagonal chalcocite.}$$

The univariant reaction

$$\text{djurleite} \leftrightarrows \text{digenite} + \text{chalcocite}$$

was found to take place at approximately (±1°C) the same temperature, resulting in a minor ambiguity of the

[3] G. Kullerud, 1953, The FeS-Zn-S system—a geologic thermometer: Norsk Geol. Tidsskr., v. 32, p. 61–147.

phase relations which could not be resolved because of the hysteresis of the reactions. No sulfur-rich deviations from Cu_2S could be detected at 180°C and 25°C, and, as hexagonal chalcocite is $Cu_{1.99}S$ at 93°C, the sulfur content apparently changes rapidly and reversibly in the 90°–140°C region. Roseboom has also shown that synthetic djurleite and its metastable tetragonal polymorph both have compositions very near $Cu_{1.96}S$ with little or no variation.

B. J. Skinner, in conjunction with F. R. Boyd and J. L. England of the Geophysical Laboratory, has demonstrated that Cu_2S has a dense high-pressure polymorph which has an X-ray powder pattern identical to metastable tetragonal $Cu_{1.96}S$. This dense Cu_2S may be quenched to 25°C and 1 atm pressure where it slowly inverts to orthorhombic chalcocite.

Stability relations in the system Cu-Ag-S

B. J. Skinner has completed investigations of the ternary system Cu-Ag-S at 250°C and 500°C which supplement Djurle's [4] data at 25°C. As all the ternary compounds lie along the join Ag_2S-Cu_2S, this binary was studied in detail, using conventional quenching techniques and high-temperature X-ray diffraction techniques. Stromeyerite (CuAgS) inverts at 92.3°C to a compound with the hexagonal high-chalcocite structure. The phase $Cu_{0.8}Ag_{1.2}S$ inverts at 94.5°C to a mixture of hexagonal high chalcocite plus $Cu_{0.45}Ag_{1.55}S$ (jalpaite) which inverts at 117°C to a body-centered cubic argentite-type structure. At higher temperatures extensive solid solutions of the hexagonal chalcocite type, body-centered cubic argentite type, and face-centered cubic digenite type all exist. Above 600°C complete solid solution of Cu_2S-Ag_2S exists with a face-centered cubic structure. None of the higher temperature phases can be quenched.

LIGHT METALS AND INDUSTRIAL MINERALS

PHOSPHATE

Northern Utah

An examination of the lower half of Permian rocks at Dry Bread Hollow, Weber County, by E. M. Schell and W. C. Gere (1–64) has revealed phosphate deposits totaling at least 46 feet of medium-grade (24 percent or more P_2O_5) and 82 feet of low grade (18 percent or more P_2O_5) rocks. This is the thickest zone of phosphate uncovered in the State, and its discovery will add substantially to the known reserves of phosphate in Utah. Trenching and sampling showed about 28 million short tons of phosphate rock in a 1-square-mile area alone. The upper part of the Permian rocks includes the Retort Phosphatic Shale Member of the Phosphoria Formation and the Ervay Carbonate Member of the Park City Formation, the first recognition of these units in this part of Utah.

[4] S. Djurle, 1958, An X-ray study on the system Ag-Cu-S: Acta Chem. Scand., v. 12, p. 1427–1436.

Southeastern Idaho

Estimates of tonnage of phosphate rock in the Stewart Flat 7½-minute quadrangle in the Peale Mountains, Caribou County, indicate that reserves in this area are among the richest in the western phosphate field. Geologic investigations by T. M. Cheney and K. M. Montgomery show that stratigraphic zones of phosphate rock, which are in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Permian), are here thicker and higher in grade than in nearby areas. In addition, structures favorable to strip mining are more extensive than previously mapped. A zone at the bottom of the phosphatic shale member in the SW¼ sec. 33, T. 8 S., R. 45 E., is more than 14 feet thick and contains more than 31 percent P_2O_5. Estimates of reserves of phosphate rock in the Stewart Flat quadrangle are:

	Millions of short tons according to grade (percent P_2O_5)		
	>31	*>24*	*>18*
Beneath less than 500 feet overburden	270	790	930
Above entry level, 6,800 feet elevation	320	930	1, 120
Total in ground	2, 030	6, 250	7, 350

Phosphate, uranium, and fluorine in southwestern Montana

Completion of stratigraphic studies of Permian rocks in southwestern and west-central Montana has included estimation by R. W. Swanson of phosphate, uranium, and fluorine resources in the Meade Peak and Retort Phosphatic Shale Members of the Phosphoria Formation. The 2 shale members are estimated to contain more than 11 billion tons of P_2O_5. Reserves of various categories, all of which occur in beds 3 feet or more thick are:

	Millions of short tons according to grade (percent P_2O_5)		
	>31	*>24*	*>18*
Above 100 feet below lowest entry level	130	560	1, 450
Total in ground	1, 000	8, 000	25, 000

Uranium contained in phosphatic rock of the above categories is shown in the table below:

	Thousands of short tons according to grade (percent P_2O_5)		
	>31	*>24*	*>18*
Above 100 feet below lowest entry level	13	41	93
Total in ground	100	500	1, 500

Fluorine occurs in the phosphate mineral in the approximate ratio of 1:10 relative to P_2O_5; total fluorine resources in the 3 grades of phosphate rock estimated on the basis of this ratio are more than 35, 200, and 500 million tons, respectively.

Phosphate and uranium in western Wyoming

According to R. P. Sheldon (1–63) the Phosphoria Formation of western Wyoming contains large resources of phosphate rock and uranium, but these do not compare in quantity with those of some other areas of the western phosphate field, notably southeastern Idaho. Phosphate reserves in the Meade Peak and Retort Phosphatic Shale Members of the Phosphoria Formation are shown in the following table (after Sheldon, 1–63, table 20):

	Millions of short tons according to grade (percent P_2O_5*)*		
	>31	*>24*	*>18*
Above entry level	300	1, 500	5, 500
Entry level to 1,000 feet below entry level	250	1, 000	3, 500
1,000–5,000 feet below entry level	850	3, 000	10, 000

Uranium contained in phosphatic rock of greater than 0.005 percent uranium content amounts to 400 thousand short tons above entry level, 200 thousand short tons from entry level to 1,000 feet below entry level, and 550 thousand short tons between 1,000–5,000 feet below entry level (Sheldon, 1–63, table 28).

The Permian sedimentary rocks of western Wyoming were laid down in two cycles, each involving the deposition of clastic rocks first, followed by carbonate, chert, and finally phosphatic shale accompanying eastward transgression of marine waters across a shelf, and then deposition of these rocks in reverse sequence accompanying regression of the sea. The Meade Peak Phosphatic Shale Member represents the climax of the first transgression, and the Retort Phospatic Shale Member the climax of the second. Phosphate is believed to have been precipitated from deep marine waters that welled upward and across the shelf, were warmed, and lost CO_2.

Miocene phosphorite, Beaufort County, N.C.

An area at least 25 miles square straddling the Pamlico River in Beaufort County is underlain by phosphorite of probable early middle Miocene age, according to J. B. Cathcart (see also the section "Zeolites"). The phosphorite bed ranges in thickness between about 20 and 100 feet, but the amount of recoverable phosphate based on 10 widely spaced drill holes drilled under contract to the Geological Survey is nearly uniform throughout the area and is about 20,000 short tons per acre. Total tonnage of phosphorite is estimated to be of the order of magnitude of 9,000 million short tons. The average grade of the phosphate pellets concentrated from this rock will probably be 30 to 31 percent P_2O_5. The phosphate pellets range from 25 to 32 percent P_2O_5 and from 0.005 to 0.010 percent uranium. The uranium analyses are from 80 samples of phosphate concentrate.

California

Field reconnaissance studies and a search of the literature by H. D. Gower and B. M. Madsen (chapter D)[4a] have revealed more than 60 separate occurrences of phosphate in California. Phosphate is distributed over a wide stratigraphic range but most commonly occurs in marine rocks of Miocene age. Most of the phosphate lies in the Coast Ranges. Localities that contain sufficient phosphate to warrant attention are the Monterey Formation in the Carmel Valley, Monterey Formation on the west side of the Salinas Valley, upper part of the Monterey Formation in the Indian Creek area on the north side of the La Panza Range, Santa Margarita Formation on the east side of the La Panza Range, lower Miocene rocks on the west side of the San Joaquin Valley, Santa Margarita Formation on the south side of the Cuyama Valley, upper Miocene rocks on the south side of Pine Mountain in northern Ventura County, lower part of the Monterey Formation in the Santa Barbara-Santa Maria area, and upper Miocene "nodular shale" of the western part of the Los Angeles Basin. The main phosphate zone at Indian Creek, about 35 feet thick, is composed of phosphate pellet beds interbedded with siliceous shale and bentonite. The pellet beds make up about 10 to 15 percent of the phosphatic zone. X-ray studies of marine phosphorites from 18 separate localities indicate that they all are composed of carbonate-fluorapatite.

Central Appalachian region

Preliminary studies by W. D. Carter of phosphate associated with the Oriskany Sandstone (Devonian) of the central Appalachian region show that phosphate occurs both as small, scattered concretionary masses at the top of the Oriskany and as nodular shales, cherts, and clays at the base of the overlying Marcellus, Needmore, and Romney Shales, and the Pottsville Formation. Generally, where one phosphate type occurs, the other is absent. In most places phosphate deposits are thin, discontinuous, and low grade, and not likely to be of economic interest, but four localities in Pennsylvania and West Virginia have phosphate which may be of sufficient grade to be economic in the future. Preliminary analyses indicate that some of these deposits contain more than 10 percent P_2O_5. In Fulton County, Pa., phosphatic shale 7 feet thick was found.

[4a] See "Contents of Geological Survey Research 1964, Chapters B, C, and D" (p. A271). This report is listed in the contents for chapter D; however, the chapter is in press and no page numbers are available.

Influence of latitude on phosphate deposition

In an evaluation of the worldwide occurrence of phosphate deposits, R. P. Sheldon (p. C106–C113) [4b] points out that Recent phosphorite occurs at warm latitudes, between the equator and the 40th parallels. Ancient phosphorites commonly lie at much higher latitudes. When the ancient phosphorites are located according to their virtual geomagnetic poles, their resulting paleolatitudinal distribution closely matches the latitudinal distribution of young phosphorites. Also, the paleogeographic settings of the ancient phosphorites match the geographic setting of the young phosphorites. Combined study of paleomagnetic and paleogeographic data thus will aid the search for ancient phosphorite.

Geochemistry of the Phosphoria Formation

R. A. Gulbrandson has calculated the average composition of the phosphorites in the Phosphoria Formation in the States of Idaho, Wyoming, Montana, and Utah with the following results:

	Weight percent		*Weight percent*
SiO_2	11.9	K_2O	0.5
TiO_2	.1	P_2O_5	30.5
Al_2O_3	1.7	CO_2	2.2
Fe_2O_3	1.1	F	3.1
MgO	.3	SO_3	1.8
CaO	44.0	H_2O (total)	2.2
Na_2O	.6	Carbonaceous material	2.1

The term "phosphorite" includes all rocks containing more than 50 percent apatite by weight. This average phosphorite composition is characteristic of marine phosphorites of the world, and as might be expected, the range of types of phosphorite in the Phosphoria includes most of those known in the world. The Phosphoria Formation is in effect a large composite phosphate deposit.

The same study shows also that the composition of the apatite mineral in the phosphorites of the Phosphoria varies significantly, and that the approximate ranges of the major components in the mineral are as follows:

	Weight percent
CaO	53.4–55.3
Na_2O	.2– 1.2
P_2O_5	36.5–40.5
CO_2	.8– 3.5
SO_3	.3– 3.1
F	3.8– 4.2

These values are common ones for apatite and do not include the extremes known in the world.

[4b] See "Contents of Geological Survey Research 1964, Chapters B, C, and D" (p. A271). This report is listed in the contents for chapter C.

BERYLLIUM

Spor Mountain, Utah

In writing of beryllium resources in Utah, W. R. Griffitts (*in* U.S. Geological Survey, 9–64) states that

> The discovery in 1960 of multi-million ton deposits at Spor Mountain, Juab County, and in 1962 near Gold Hill, Tooele County, has shown that Utah contains the world's largest known beryllium deposits. As a result of the successful exploration of the Spor Mountain deposits, the beryllium industry is beginning a shift from the use of imported high-grade ore to the use of domestic low-grade ore. Such a shift will permit greatly expanded consumption of beryllium and will provide a stable domestic source of ore. Thus great changes in the structure of the industry and in the amount and diversity of use of the metal and its compounds can be expected soon, largely based upon Utah resources.
>
> Resources to support active mining are assured, as at least 15 million short tons of material averaging at least one-half percent BeO are available in the Spor Mountain and Gold Hill areas.

The amount of beryllium in these deposits is about 75 times the present annual consumption of beryllium in the United States. Griffitts states also that the same districts probably contain a similar amount of material averaging 0.1 to 0.5 percent BeO. Enormous tonnages of rock averaging 0.01 to 0.1 percent BeO are present in the Sheeprock Mountains and Gold Hill area.

A low-angle fault in western Juab County, Utah, described in the section "Eastern Nevada and Utah" under "Regional Geology, Basin and Range Region," conceals tuff that probably is correlative with tuff that contains the large beryllium deposits at Spor Mountain, and may conceal additional deposits.

The location of the Spor Mountain, Gold Hill, and Sheeprock areas is shown on figure 2, together with a geologic map of the beryllium deposits at Spor Mountain. Geology of the beryllium deposits at Spor Mountain has been described by Staatz and Griffitts [5] and Staatz.[6]

Sheeprock Mountains and near Gold Hill, Utah

Geology of the beryllium-bearing granite in the Sheeprock Mountains has been described by R. E. Cohenour.[7] According to Griffitts (*in* U.S. Geological Survey, 9–64) a group of exceptionally large beryllium deposits was found by the Vanguard Research Co. in

[5] M. H. Staatz and W. R. Griffitts, 1961, Beryllium-bearing tuff in the Thomas Range, Juab County, Utah: Econ. Geology, v. 56, p. 941–950.

[6] M. H. Staatz, 1963, Geology of the beryllium deposits in the Thomas Range, Juab County, Utah; U.S. Geol. Survey Bull. 1142–M, 36 p.

[7] R. E. Cohenour, 1963, Beryllium and associated mineralization in the Sheeprock Mountains; *in* Beryllium and uranium mineralization in western Juab County, Utah: Utah Geol. Soc. Guidebook to the geology of Utah, no. 17, p. 8–13.

1962 in the Rodenhouse Wash area about 3 miles southeast of Gold Hill, Utah. In this area, near the center of a stock of quartz monzonite, beryllium-bearing veins are numerous in a belt about 2 miles long. Individual veins are tens of feet in thickness and hundreds of feet in length. The veins are a fine-grained mixture of quartz, calcite, adularia, and a beryllium mineral (apparently the silicate, bertrandite). The veins are in the northeast-trending fracture zone shown by Nolan.[8]

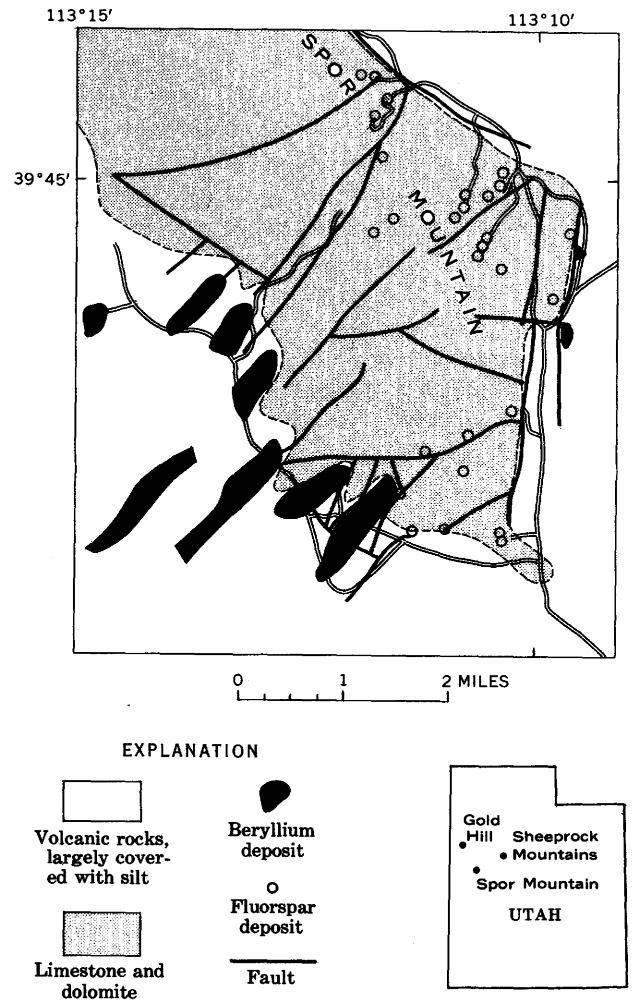

FIGURE 2.—Geologic map showing location of beryllium deposits mapped by W. R. Griffitts at Spor Mountain, Utah. Index map shows location of Spor Mountain, Gold Hill, and Sheeprock Mountains.

Lake George area, Colorado

Beryllium-rich granites and associated pegmatites and greisens occur in scattered localities in central Colorado. Production from the Boomer mine in the Lake George area is comparable with that of exceptionally large pegmatites in different parts of the world. New chemical data obtained by C. C. Hawley (1–64, 2–64) for the Lake George area, Front Range, show that, ideally, the beryllium-bearing greisens consist of inner berylliferous and aluminous zones encased in a nearly barren, relatively siliceous zone. The deposits contain ore bodies in the form of veins, pipes, and complex irregular masses, localized by fissures, rock contacts, and rock units of favorable composition or orientation. The main deposit, that at the Boomer mine, is a body of complex form localized by a combination of nearly vertical northeast-striking fissures, a low-angle north-striking set, and the southern contact of the so-called Boomer stock. Most of the other deposits are much simpler in form.

Mount Antero area, Colorado

Continuing work in the Mount Antero area by W. N. Sharp seems to support the classical interpretation of geochemical concentration of beryllium in late-stage granitic residual liquids. Accumulations of beryllium in the Mount Antero leucogranite stock are virtually restricted to late derivatives of the magma, and these accumulations have collected mostly within a fine-grained facies which forms a high lobe of the stock. Small aggregate clots of beryl in the fine-grained granite segregation contain practically all the concentrated beryllium. The aggregate clots have a texture like the surrounding granite, but the place of quartz is occupied instead by beryl.

Throughout the Antero stock and its outliers, beryllium shows a general but limited dispersion in the rock-forming minerals of the granite. The average beryllium content of the granite stock, exclusive of the aggregate clots of beryl, is somewhat higher (7–9 parts per million) than the average value commonly accepted for granite (5 ppm), but the actual range of values is wide, 4 to 20 ppm. The beryllium content of the stock as a whole clearly is higher than the consistent 2 to 3 ppm of the surrounding quartz monzonite host rocks. Greisenized outliers to the main stock have sharp local variations in beryllium content. Generally, the beryllium content (3–4 ppm) is below that of unaltered granite. However, small topaz-greisen zones range from 20 ppm to about 2 percent beryllium. In addition, common small beryl-bearing veinlets pervade the greisenized granite.

Sierra Cuchillo, N. Mex.

The discovery in 1961 of beryllium in volcanic rocks in the Sierra Cuchillo, Socorro County, has recently

[8] T. B. Nolan, 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

been announced.[9] The occurrence is about 5 miles north of the helvite deposits at Iron Mountain [10] in a north-striking fault zone in latite. From field and laboratory work by W. R. Griffith and D. R. Shawe, it has been ascertained that the grade of rock locally exceeds 1 percent BeO, and that the beryllium probably occurs as bertrandite in latite that has been brecciated, silicified, altered to clay minerals, and stained by iron and manganese oxides along the fault zone. The deposit lies about 10 miles northwest of a fluorspar-uranium deposit near Monticello, N. Mex., and is in an area of topaz-bearing rhyolite. The similarity to the geologic setting of the Spor Mountain deposits suggests the possibility that additional volcanic-associated deposits may be discovered in the region.

Beryl in Swain County, N.C.

R. A. Laurence, together with Tennessee Valley Authority geologists J. H. Davis, J. M. Fagan, and R. C. Hale, has examined a newly discovered pegmatite in Swain County. The pegmatite is too small to be of economic value, but it contains 2 or 3 percent beryl in large crystal aggregates, and its finding extends the Bryson City pegmatite district to the southwest by at least 2 miles. Previously, beryl has been reported only as a minor constituent in 4 of 36 pegmatite mines in the district.

Beryllium associated with granite in Alaska

According to C. L. Sainsbury (1–64), some of the beryllium deposits in the Lost River area of the western Seward Peninsula are localized by a combination of structural and petrologic elements of different ages. Areas especially favorable for ore occur where granite plutons of Late Cretaceous age pierce, or underlie at shallow depth, thrust faults of pre-Late Cretaceous age. Normal faults and dikes of acidic and mafic composition of postgranite age apparently have guided ore solutions into areas of fracturing created by thrust faults. Hence, intersections of thrust faults and granite are favorable places to seek undiscovered ore bodies.

At the contact of the granite along Tin Creek, the beryllium mineral helvite [$(Mn, Fe, Zn)_8(BeSiO_4)_6S_2$] occurs in banded magnetite-fluorite "ribbon rock" similar to that at Iron Mountain, N. Mex. The beryllium-fluorite veins in which most of the beryllium is concentrated lie outside of the magnetite-fluorite rock, which suggests that similar relations may exist elsewhere.

[9] M. H. Milligan, quoted in Engineering and Mining Journal, 1963, v. 164, no. 12, p. 154.

[10] R. H. Jahns, 1944, Beryllium and tungsten deposits of the Iron Mountain district, Sierra and Socorro Counties, New Mexico: U.S. Geol. Survey Bull. 945–C, p. 45–79.

Beryllium content of different volcanic rock types

Spectrographic and chemical analyses of 1,172 saturated and over-saturated volcanic rocks compiled by Stanley Bernold and D. R. Shawe (1–64) indicate that beryllium content has a marked tendency to increase with silica content. The beryllium content of rocks containing more than about 76 percent silica, however, tends to decrease. Five hundred and eighty-one volcanic rocks that contain more than 70 percent silica comprise 3 different rock types—glasses, flow rocks, and tuffs—that show interesting variations from the average beryllium-silica relation. In volcanic glasses (198 rocks) and flow rocks (102 rocks), beryllium increases with silica to a maximum at about 75 percent silica, and drops noticeably in rocks with higher silica. On the other hand, in volcanic tuffs (281 rocks), beryllium increases with silica to the highest silica compositions. Moreover, the average beryllium content of the volcanic tuffs containing more than 70 percent silica (3.4 parts per million Be) is significantly lower than that of volcanic glasses (4.8 ppm) and flow rocks (4.4 ppm). These facts suggest fundamental differences in composition and genesis between tuffs and other volcanic rocks that may bear on the origin of beryllium deposits in volcanic and associated rocks, but have yet to be evaluated.

FLUORSPAR

Browns Canyon district, Colorado

Fluorspar deposits of the Browns Canyon district, Chaffee County, have yielded about 130 thousand short tons of concentrates and contain large resources, according to R. E. Van Alstine. They occur chiefly as epithermal veins along steep northwest-trending normal faults in Tertiary volcanic rocks and Precambrian igneous and metamorphic rocks. One of the faults contains fluorspar almost continuously for about 2,600 feet. Maximum thickness of the fissure veins is about 40 feet, and the CaF_2 content ranges from about 25 to 75 percent. The veins consist mainly of fine-grained fluorite and quartz. Measured and indicated fluorspar is estimated at 250 thousand short tons containing more than 35 percent CaF_2 and 150 thousand short tons containing 15 to 35 percent CaF_2; an additional 650 thousand short tons of fluorspar in the above grade categories is inferred. More than 1 million short tons of fluorspar averaging about 20 percent CaF_2 is estimated for the nearby Poncha district, Chaffee County. Fluorspar deposits in both districts are regarded as resources rather than reserves, as they are not currently being mined.

L. C. Huff and Van Alstine collected soil samples (sieved to −80 mesh) at 50-foot intervals along 3 traverses across a vein in the Browns Canyon district, and alluvium samples (sieved to −1 mm) upstream and downstream from the vein to test the use of fluorine as an indicator of fluorite. Forty-four analyses for fluorine were made by S. M. Berthold. Fluorine ranged from 1.5 to 5 percent in samples of soil overlying and downslope from the vein. These values contrasted with as little as 0.06 percent in a sample 150 feet upslope from the vein and 0.08 percent in a sample 250 feet downslope from the vein. The average fluorine content of the earth's crust has been estimated as 0.08 percent.[11] The geochemical anomaly associated with the fluorspar vein represents a 6 to 14 fold increase over the average fluorine value for samples of residual soil overlying the wallrocks (Precambrian gneiss and quartzite and Tertiary rhyolitic welded tuff). A sample of alluvium 1,000 feet downstream from the vein has 3 times as much fluorine as one collected 300 feet upstream from the vein. Panning of 10-pound samples of this alluvium increases the fluorine concentration 6 to 8 times.

Cave-in-Rock district, Illinois

Work by D. M. Pinckney in the Cave-in-Rock fluorspar district, Hardin County, has shown that ore bodies occur in gently dipping favorable beds of limestone (Mississippian) beneath thin shaly layers. Joints in zones parallel or perpendicular to major faults permitted access of hydrothermal solutions to favorable beds at a few centers. Solutions spread from these centers, causing solution of the favorable and underlying beds, and in most places slumping or collapse of overlying beds, and deposition of ore in favorable beds. Many stages of deposition have been identified, both on the basis of successions of minerals and successions of zones within crystals. Minerals of the earlier stages are largely confined to the centers of mineralization or the channelways leading away from the centers. Minerals of the later stages either completely surround the zones of earlier minerals, or lie at new centers that became active during later stages of mineralization.

BAUXITE AND CLAY

Clay in eastern Washington and adjacent Idaho

Clay studies in Spokane County, Wash., and in nearby Idaho by J. W. Hosterman show that five genetic types of clay are available locally for making clay products. They are (1) brown silty clay of the Palouse Formation, (2) varicolored clay of the Latah Formation, (3) white residual clay derived from granodiorite and related rocks, (4) bluish-gray residual clay derived from Columbia River Basalt, and (5) gray clay from Pleistocene lake beds. The first three have been or are now used for making refractory products and structural bricks. Three areas containing white clay of the Latah Formation have been found that are not described in the literature. One of these is of potential economic importance, for it extends over at least 1 square mile and contains more than 35 percent Al_2O_3 over a 10-foot thickness in the discovery hole on the west border of sec. 17, T. 48 N., R. 5 W., Kootenai County, Idaho. Ilmenite is abundant in residual clays derived from basalt, and is a potential byproduct. Monazite is found in residual clay derived from granodiorite, but it has a low ThO_2 content.

Clay in Maryland

Information gathered recently in Maryland by M. M. Knechtel, in collaboration with the staff of the Norris (Tennessee) Research Laboratory of the U.S. Bureau of Mines, amplifies the results of reconnaissance studies which led to discovery of large deposits of bloatable clay and shale. Materials believed to be suitable for lightweight-aggregate production occur in sedimentary strata of two formations, the St. Mary's Formation (Miocene) exposed in Calvert and St. Mary's Counties, and the Martinsburg Shale (Ordovician) exposed in Washington County. The State's first plant designed for manufacture of rotary kiln-fired lightweight aggregate will soon be in operation in Frederick County, at a site along State Route 550 approximately three-quarters of a mile southeast of Woodsboro. Tentative plans call for production to begin late in 1964 for shipment to Washington, D.C., Baltimore, Md., and other nearby localities. Ample supplies of bloatable shale, suitable for firing in rotary kilns, are available near the plant site in strata of the Frederick Limestone (Cambrian) which crop out along a northeasterly-trending synclinal trough. The only competitive lightweight product heretofore manufactured in Maryland has been expanded furnace slag, a byproduct of steel making at Sparrows Point, which has for many years been marketed for use as aggregate in the city of Baltimore and its immediate vicinity.

Bauxite in Hawaii

S. H. Patterson [12] has found allophane and alumina-silica gel in weathered basalt associated with low-grade bauxite deposits on Maui, Hawaii. The chemical com-

[11] V. M. Goldschmidt, 1958, Geochemistry: London, Oxford University Press, p. 74.

[12] S. H. Patterson, 1963, Halloysitic underclay deposits and occurrence of an alumina-silica gel and an allophane-like mineraloid in Hawaii [abs.]: 12th Natl. Clay Minerals Conf., Atlanta, Ga.

position of the allophane is approximately 50 percent Al_2O_3, 26 percent SiO_2, 1 percent Fe_2O_3, and 0.1 percent TiO_2, and the loss on ignition is 25 percent. The alumina-silica gel is approximately 4.9 percent Al_2O_3, 2.2 percent SiO_2, and 0.3 percent Fe_2O_3, and the water loss with air drying is approximately 90 percent. After air drying, the composition of the gel is very similar to that of the allophane. The similar compositions of these two amorphous materials and their close relation in the field suggest the formation of allophane by dehydration of gel. The manner in which the allophane gel occurs is similar to that of mixtures of gibbsite and hollysite that are common in weathered rocks on Maui, and both types of amorphous materials are probably intermediate stages in the formation of these minerals.

Attapulgite and fuller's earth in Georgia

Mapping of the geologic structure of a limestone aquifer in the fuller's earth clay-mining area in southwestern Georgia has shown that all existing mines in deposits of attapulgite and fuller's earth are near the axis of a southwest-plunging structural trough (Sever, p. B116–B118). The clay was deposited in a basin localized either by continued downwarping or by compaction of the underlying unconsolidated deposits in the deeper part of the trough. Recognition of this relation and delineation of the structural trough should aid in prospecting for other economically valuable deposits of this clay.

ZEOLITES

Western Mojave Desert, Calif.

In recent years there has been accelerated interest in natural zeolites for industrial use. Industry now uses synthetic zeolites almost exclusively, but as economic methods are developed to convert natural material into a commercial product, large natural deposits may become important.

Study by R. A. Sheppard and A. J. Gude, 3d (p. C114–C116) of tuffaceous rocks of Tertiary age from the western Mojave Desert and vicinity, southern California, has shown widespread zeolitization there. Vitric material in the tuffaceous rocks generally altered partly or wholly to zeolites, clay minerals, silica minerals, and (or) potash feldspar. The most abundant zeolite is clinoptilolite, but some beds are rich in analcime, erionite, and phillipsite. Mordenite is a minor constituent of some beds. Potentially economic deposits of clinoptilolite, analcime, and erionite have been located.

Atlantic Coastal Plain

X-ray diffractometer studies of the slime fraction (−200 mesh) of samples of the phosphorite unit (Miocene) in Beaufort County, N.C., by Theodore Botinelly showed a zeolite mineral (probably clinoptilolite), cristobalite, and an amorphous material (probably glass). The minerals indicate the presence of altered volcanic ash. The samples were collected and prepared by J. B. Cathcart from cores of 2 drill holes about 20 miles apart. The minerals were not present in samples of the underlying Castle Hayne Limestone (Eocene), nor in a sample of the overlying Yorktown Formation (Miocene). This is the first known occurrence of zeolite in the Tertiary sediment of the Atlantic Coastal Plain.

EVAPORITES AND BRINES

Searles Lake, southern California

Geologic and petrographic investigations of the Searles Lake evaporite deposit (Quaternary), San Bernardino County, by G. I. Smith and D. V. Haines has shown many systematic differences among the assemblages of evaporite minerals that are related to their stratigraphic distribution. Some of the 25 evaporite minerals at Searles Lake formed as primary deposits on the bottoms of lakes, but most formed after burial when the primary suite recrystallized into larger crystals of the same or different species. A systematic habit variation among some of the recrystallized species suggests that, although their postburial growth reflects the lower free energy of larger crystals, their differences in crystal form also reflect kinetic factors controlled by differences in the physical and chemical environment extent at the time they grew. In spite of extensive recrystallization, the present mineralogy of the deposit is close to that of the primary deposit, and this permits an approximation of the composition, salinity, and prevailing temperatures in the several lakes responsible for the deposits.

A theoretical study by H. P. Eugster and Smith of the Searles Lake brines is summarized in the section "Experimental Geochemistry."

Geothermal brines near Niland, Calif.

Near Niland, Imperial County, at the southeast end of the Salton Sea, geothermal brines pumped from deep drill holes [13] are being investigated by private companies as possible sources of geothermal energy and chemicals. Subsurface temperatures are in the order of 300°C. Some brines contain nearly 30 percent of dissolved matter, of which about 7 percent is potassium. (See also sections "Isotopic Tracer Studies," "Field Studies in Petrology and Geochemistry," and "Saline Water Resources.")

[13] D. E. White, E. T. Anderson, and D. K. Grubbs, 1963, Geothermal brine well; mile-deep drill hole may tap ore-bearing magmatic water and rocks undergoing metamorphism: Science, v. 139, p. 919–922.

Borate in Nevada

In a review of data on borate deposits in Nevada, W. C. Smith points out that Nevada deposits were the chief source of borate in the United States during the period 1872–92. Some borate was produced in 1921–28 and in 1939, but in other years the Nevada producers were unable to compete with large producers in California. The largest reserves of borate known in Nevada are in deposits of colemanite at White Basin and at Calleville Wash, Clark County. Their reserves are estimated to be about 2 million short tons. The borate marshes that produced most of the early-day borax, including those of Mineral and Esmeralda Counties, contain only thin surficial deposits that seem unworkable in the foreseeable future.

Bromine in evaporites of Utah and Colorado

X-ray fluorescence analyses of the marine saline rocks of the Paradox Basin by O. B. Raup show that the bromine content ranges from 0.008 to 2.0 percent by weight. Salinity gradients contoured by bromine distribution make it possible to outline in detail the configuration of the evaporite basin during each evaporite cycle, thereby aiding in the location of potentially commercial potash deposits.

OTHER LIGHT METALS AND INDUSTRIAL MATERIALS

Lithium in Utah

The lithium content of bedded rhyolitic tuff is unusually high at the Roadside beryllium deposit, Spor Mountain, Juab County, according to D. R. Shawe, Wayne Mountjoy, and Walter Duke (p. C86–C87). Li_2O averages 0.22 percent in 18 representative samples. It is probably present chiefly in montmorillonite. Though perhaps not economic by itself, the lithium may well be a byproduct if the deposit is worked for beryllium.

Barium in southwestern Arkansas

D. A. Brobst has applied a relatively simple turbidimetric field chemical test developed by Ward and others[14] to geochemical prospecting for barite in the Caddo Gap and DeQueen quadrangles. Bedded barite deposits in the Stanley Shale (Mississippian) proved to have barium halos that display a gradual outward decrease in barium and generally extend less than 150 feet in stratigraphic thickness above and below the ore zone. The target areas of barite deposits in the generally steeply dipping Stanley Shale therefore are small. Samples at intervals of 300 feet across strike would probably be required to thoroughly prospect this formation. Halos around deposits in the Trinity Group (Cretaceous) are much more irregular. Barite ore bodies in the Trinity Group that are covered by more than a few feet of overburden probably cannot be identified by field chemical analysis of samples from the surface.

Glauconite in the central Appalachian region

According to W. D. Carter, glauconite, mined as a soil conditioner and water softener in New Jersey, is also found in the central Appalachians. It occurs mainly as sandstone and shale in the Huntersville Chert of Price (1929) (Devonian) of eastern West Virginia and southwestern Virginia, where it is as much as 4 feet thick. Preliminary analyses indicate that glauconite containing 3 to 7 percent potassium is found in Pocahontas County, W. Va., and Montgomery County, Va.

Silica in the Great Basin and Appalachian regions

According to K. B. Ketner, several formations in the Great Basin contain thick quartzite units of remarkable purity. Among these are the Big Cottonwood Formation (Precambrian), Tintic Quartzite (Cambrian), Valmy Formation (Ordovician), and Eureka Quartzite (Ordovician). The high purity of quartzite in the Big Cottonwood and Valmy Formations was unexpected.

Work by W. D. Carter shows that the Oriskany Sandstone (Devonian) and Tuscarora Quartzite (Silurian) contain most of the silica resources of the central Appalachian region. The Oriskany Sandstone ranges from 0 to 250 feet in thickness and is thickest along a narrow south-trending belt extending from south-central Pennsylvania into northeastern West Virginia and northwestern Virginia where it is mined for glass sand. The Tuscarora Quartzite has been mined for refractories, mainly in Pennsylvania, and constitutes an even larger resource of silica than the Oriskany, although in most places it is more difficult to mine.

Pegmatites and related deposits

As a result of geologic mapping in the southeast corner of the Franklin quadrangle, Macon County, N.C., F. G. Lesure has located numerous small mica prospects and three emery prospects, and extended knowledge of a previously known area of kyanite-bearing rocks.

RADIOACTIVE MINERALS

URANIUM IN SANDSTONE

Many similarities and some differences in the geologic setting, form, habits, and mineralogy of uranium

[14] F. N. Ward, H. W. Lakin, F. C. Canney, and others, 1963, Analytical methods used in geochemical exploration by the U.S. Geological Survey: U.S. Geol. Survey Bull. 1152, p. 44–45.

deposits in sandstone, conglomerate, and mudstone of diverse ages are recorded for widely separated areas such as Monument Valley, Ariz. (Witkind and Thaden [15]); Deer Flat, Utah (Finnell and others [16]); Capitol Reef, Utah (Smith and others, 1–63); Lees Ferry, Ariz. (Phoenix, 1–63); Edgemont, S. Dak. (Gott and Schnabel [17]); and the Lehighton quadrangle, Pennsylvania (Klemic and others, 2–63). Although sandstone deposited as channel fills directly or indirectly controls the occurrence of uranium deposits in Triassic rocks in Monument Valley, at Deer Flat, and many of the deposits in Cretaceous rocks near Edgemont, the selectivity noted among channels is still incompletely understood. Also noteworthy is the resemblance between size and form of some features in a deposit in rocks of Devonian age near Penn Haven Junction, Pa., and those in deposits in the Morrison Formation in the West.

Ambrosia Lake and Laguna districts, New Mexico

The Ambrosia Lake and Laguna uranium districts were described in five papers, by L. S. Hilpert,[18] R. E. Thaden and E. S. Santos,[19] H. C. Granger,[20] E. S. Santos,[21] and R. H. Moench,[22] of the Geological Survey, in the comprehensive memoir on the Grants uranium region, sponsored in part by the Society of Economic Geologists.

Geologic evidence presented by R. H. Moench [22] tentatively dates uranium deposition in the Laguna district to the period between early, near-surface deformation of the Jurassic host rocks and probable early Tertiary tilting in the southeast part of the San Juan Basin. Moench suggests that the uranium deposits formed in Jurassic time before the host rocks were deeply buried and possibly when they were exposed at the surface. The uranium deposits may have formed where the flow of near-surface ground water was impeded by the stratigraphic and early postdepositional tectonic structures that characterize the mineral belt.

H. C. Granger has found that oxidation taking place several hundred feet below the ground-water table in the Ambrosia Lake uranium district releases some selenium from the pyrite which is normally present in the unoxidized rocks. The pyrite contains as much as 1.5 percent selenium. As the pyrite is oxidized, some selenium is redistributed to form ferroselite. Further oxidation of the ferroselite-rich zone destroys the ferroselite, and the selenium is carried ahead of the oxidation front where some of it is deposited as native selenium. As a result, oxidation fronts defined by the limits of destruction of pyrite are characterized by concentrations of selenium in different forms on opposite sides of the interface.

Shirley Basin, Wyo.

From the spatial relation of uranium deposits to large tongues of altered sand, and from laboratory studies of elements in those deposits, E. N. Harshman concludes that uranium was carried into the lower part of the basin by oxidizing slightly acid or slightly alkaline ground water, moving laterally through permeable sand in the Wind River Formation. Uraninite was apparently deposited at an interface between the uranium-bearing ground water and semistagnant ground water in the lower part of the basin. Earlier concepts that uranium was carried as a carbonate complex and was reduced by H_2S of biogenic origin are compatible with data on the Shirley Basin deposits.

Texas coastal plain

D. H. Eargle reports the discovery by a mining company of a significantly large concealed deposit of uranium ore in Karnes County, Tex., in the vicinity of radioactivity anomalies previously known from drilling by the Geological Survey and by companies. This discovery suggests that other concealed deposits may be present in this part of the Gulf Coastal Plain. The deposit is also possible evidence that uranium migrated downdip in ground water and was precipitated in a reducing environment.

Results of a study of uranium and helium in the Panhandle gas field, Texas, which originally contained the largest commercial helium reserve in the United States, have been presented by A. P. Pierce, G. B. Gott, and J. W. Mytton (1–64). The highest concentration of uranium is in the caprocks, which have been estimated to contain between 10 and 20 parts per million through a thickness of about 250 feet. The uranium in these rocks is concentrated in

[15] I. J. Witkind and R. E. Thaden, 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona: U.S. Geol. Survey Bull. 1103, 171 p.

[16] T. L. Finnell, P. C. Franks, and H. A. Hubbard, 1963, Geology, ore deposits, and exploratory drilling in the Deer Flat area, White Canyon district, San Juan County, Utah: U.S. Geol. Survey Bull. 1132, 114 p.

[17] G. B. Gott and R. W. Schnabel, 1963, Geology of the Edgemont NE quadrangle, Fall River and Custer Counties, South Dakota: U.S. Geol. Survey Bull. 1063–E, 190 p.

[18] L. S. Hilpert, 1963, Regional and local stratigraphy of uranium-bearing rocks, *in* Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 6–18.

[19] R. E. Thaden and E. S. Santos, 1963, Map showing the general structural features of the Grants district and the areal distribution of the known uranium ore bodies in the Morrison Formation; *in* Geology and technology . . . : New Mexico Bur. Mines and Mineral Resources Mem. 15, map opposite p. 20.

[20] H. C. Granger, 1963, Mineralogy, *in* Geology and technology . . . : New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 21–37.

[21] E. S. Santos, 1963, Relation of ore deposits to the stratigraphy of host rocks in the Ambrosia Lake area, *in* Geology and technology . . . : New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 53–59.

[22] R. H. Moench, 1963, Geologic limitations on the age of uranium deposits in the Laguna district, *in* Geology and technology . . . : New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 157–166.

asphaltite which contains about 1 percent uranium. The uranium and associated metals are thought to have been derived from the rocks in which the asphaltite now occurs, and were concentrated in petroleum compounds. The distribution of uraniferous asphaltite indicates that it is the source of the abnormally high radon in the gases from a number of wells.

URANIUM AND THORIUM IN CRYSTALLINE ROCKS

Southeastern Piedmont

A type of radioactive deposit not previously recognized in the southeastern Piedmont has been reported by H. W. Sundelius and Henry Bell. The radioactive deposit, at the Heglar prospect in Cabarrus County, N.C., contains disseminated pyrite, other sulfides, and rare-earth elements in an andradite-opal-chalcedony-quartz gangue. The deposit occurs within a regional radiometric anomaly near the boundary between greenschist facies rocks of the Carolina slate belt and albite-epidote amphibolite facies rocks of the Charlotte belt. It appears to be related to a cross-cutting, highly sheared quartz monzonitic body.

Thorium in the Wet Mountains, Colo.

In the Rosita quadrangle, Custer County, Q. D. Singewald and R. B. Laughon have found that radioactive anomalies due to thorium are in Precambrian rocks mainly in the northwest quarter of the quadrangle and that all strong anomalies are northeast of a northwesterly trending line about through the center of sec. 35, T. 22 S., R. 71 W. This northeast corner represents part of a poorly defined belt about 5 miles wide that trends north-northwest and also contains most of the thorium-bearing veins in the Mount Tyndall quadrangle just to the north.

MINOR ELEMENTS

RARE EARTHS AND NIOBIUM

The calcium yttrium silicate-carbonate mineral, cenosite, was found in a thorite vein near Porthill, Idaho, by J. W. Adams and M. H. Staatz—the second known occurrence of the mineral in the United States.

Niobium, rare earth, and thorium minerals discovered in the alkalic rocks of Gem Park near Hillside, Colo., by F. A. Hildebrand and R. L. Parker include, in addition to lueshite,[23] pyrochlore, fersmite, fergusonite, columbite, thorianite, and monazite. Gem Park is the second known locality for the occurrence of fersmite in the United States and the first for thorianite in Colorado.

[23] R. L. Parker, J. W. Adams, and F. A. Hildebrand, 1962, A rare sodium niobate mineral from Colorado, Art. 61, *in* U.S. Geol. Survey Prof. Paper 450–C, p. C4–C6.

Geochemical exploration by R. L. Parker, F. A. Hildebrand, Uteana Oda, and A. P. Marranzino has shown that part of the Gem Park alkalic intrusive body contains anomalous niobium and thorium. The niobium content of samples within the anomaly ranges from 100 to greater than 2,000 parts per million, and highest radioactivity within the anomaly occurs where the content of niobium is greatest.

SELENIUM AND TELLURIUM

An extremely sensitive method for the quantitative determination of tellurium has been developed by H. W. Lakin and C. E. Thompson (2–63), permitting the investigation of tellurium in all geochemical environments.

Tellurium in amounts ranging from 5 to 125 parts per million has been found in manganese nodules from the floor of the Pacific and Indian Oceans (Lakin, Thompson, and Davidson, 3–63). The nodules represent the first recognized high tellurium concentration in a sedimentary cycle.

Lakin, D. F. Davidson, and Thompson have found also that the tellurium and selenium content of volcanic sulfur exceeds that of hot-springs sulfur, and that their content in hot-springs sulfur exceeds that in sulfur of sedimentary origin. Such distribution suggests that tellurium and selenium are much more mobile in the gaseous state than in solution in water.

Investigation of the distribution of tellurium by G. B. Gott and J. H. McCarthy, Jr., around the Ruth porphyry copper deposit near Ely, Nev., shows that the tellurium is most concentrated in a halo surrounding the copper.

ORGANIC FUELS

The Geological Survey conducts a variety of investigations that may be of direct or indirect value to private organizations in their exploration for organic fuels. These investigations include regional geologic and geophysical mapping and stratigraphic, paleontologic, and sedimentation studies which are described under other headings. Only studies pertaining directly to fuels, geochemistry of fuels, and fuels resources are reported here.

COAL

Southwestern Pennsylvania

The first two of a series of geologic-quadrangle maps of areas where the Pittsburgh coal bed is extensively mined southwest of Pittsburgh, Pa., were published in 1964 (Berryhill and Swanson, 2–64; Berryhill, 1–64). These maps show structure contours of the Pittsburgh coal, the general lithology of the Upper Pennsylvanian and Lower Permian stratigraphic units, and also the distribution and outcrop pattern of several poorer grade or thinner coal beds currently uneconomic to mine, including the Waynesburg and Washington coal beds.

The lower member of the Pittsburgh Formation is commonly a sandstone in the area of Washington, Pa., and in places occupies broad channels that cut into the Pittsburgh coal bed, constituting a significant economic and mining problem. B. H. Kent and S. P. Schweinfurth report that in the western part of the area this member is generally a sheetlike sandstone, but that the sandstone-filled channels become more numerous and complex toward the southeast.

Western Pennsylvania

A report by E. D. Patterson (1–63) on the geology and coal resources of Beaver County, which is northwest of Pittsburgh, Pa., gives estimates of original reserves of high-volatile bituminous coal as 2,517 million tons, and remaining reserves of 2,489 million tons. Most of these reserves are in the Lower and Middle Kittanning coal beds and the Lower and Upper Freeport coal beds, all in the Allegheny Formation of Pennsylvania age.

Eastern Pennsylvania

Recent studies by H. H. Arndt in the Western Middle Anthracite field and by G. H. Wood, Jr., in the Southern Anthracite field show that the fixed-carbon and volatile matter in the coal are related to geographic location and structural position. Regionally, the percentage of fixed carbon increases and volatile matter decreases eastward in the direction of regional plunge and greater original depth of burial of the coal beds. On a smaller scale, there is a marked parallelism of lines of equal fixed-carbon and volatile-matter content with fold axes, the fixed carbon being greater and volatile matter less along synclinal axes; the fixed carbon is less and volatile matter greater along anticlinal axes.

Southeastern Kentucky and northern Tennessee

K. J. Englund reports that an appraisal of coal resources in rocks in Pennsylvania age in a four-quadrangle area of parts of Scott and Campbell Counties, Tenn., and McCreary and Whitley Counties, Ky., indicates total reserves of about 1 billion tons in beds exceeding 14 inches in thickness. This estimate includes data on several beds with previously unreported reserves.

Iowa

A recent investigation by E. R. Landis shows that coal-bearing rocks of Pennsylvanian age underlie some 20,000 square miles of the State of Iowa. Estimated original reserves of bituminous coal total 7.2 billion short tons, remaining reserves 6.5 billion tons, and 1.8 billion tons can be categorized as measured and indicated reserves in beds more than 42 inches thick.

Northern New Mexico

The geology and coal resources of the southwestern part of the Raton coal field in Colfax County, N. Mex., are described in a report by A. A. Wanek (2–63). The map area covers about 750 square miles and contains reserves estimated at nearly 1.5 billion tons of high-volatile bituminous coal. The area also includes rocks of Cretaceous and Pennsylvanian age that are possible reservoirs for oil and gas.

Detailed study of the coal deposits of the Upper Cretaceous Fruitland Formation in the San Juan basin, Colorado and New Mexico, by J. S. Hinds (chapter D) indicates that on an "as received" basis the Btu values are highest in the northwest part of the basin. On a "moisture and ash-free" basis, however, the highest Btu values are in the northeast part of the basin corresponding to the youngest coals.

Montana

The geology and the distribution of Upper Cretaceous coal beds in the Livingston coal field in south-central Montana are shown on eight quadrangle maps by A. E. Roberts (1–64 to 8–64) published in 1964. More than 260 million tons of high-volatile bituminous coal, much of it of coking quality, remain unmined in this coal field.

Alaska

The coal-bearing Kenai Formation of Tertiary age underlies a lowland region of at least 5,000 square miles at the head of Cook Inlet, between the Susitna River and the Alaska Range in southern Alaska, according to F. F. Barnes. Potentially valuable lignite and subbituminous coal deposits lie mainly within a 400-square-mile area in the southern part of the region, and include at least 2 beds 30 to 50 feet thick that have been traced for several miles. Indicated reserves in beds more than 2½ feet thick and within 1,000 feet of the surface total about 2.4 billion tons; about 2.2 billion tons of this is in beds more than 10 feet thick.

PETROLEUM AND NATURAL GAS

Most of the studies contributing to the fund of stratigraphic, geophysical, and paleontologic data upon which the petroleum industry relies are reported under appropriate regional and topical headings.

Yellowstone National Park, Wyo.

For more than a century oil seeps and deposits of bitumen have been known in and near Yellowstone Park. J. D. Love investigated three of these occurrences with J. M. Good, of the National Park Service, and they interpret them to be surface expressions of "natural refineries." Light aromatic oil is probably being distilled from underlying Cretaceous and perhaps older organic-rich sedimentary rocks by somewhat deeper igneous intrusives. Interestingly, the oil has a low sulfur content, but the seeps are associated with hot springs and sulfur deposits.

North-central Wyoming

The geology of the east Thermopolis area in Hot Springs and Washakie Counties is described in a report by G. H. Horn (1–63). The map area, with accompanying text, covers about 480 square miles in the southeastern part of the Bighorn Basin, and the 10 oil and gas fields in the area are described.

Southeastern Wyoming

A geologic map at a scale of 1:24,000 by H. J. Hyden [24] includes an area of active petroleum exploration along the Rock River–Dutton Creek anticline in Carbon County. This map shows a series of previously unmapped northwest-trending reverse faults on the west flank of the anticline; these or similar faults presumably trap oil in Cretaceous rocks at depth in this area.

Northern Alaska

A report by R. L. Detterman, R. S. Bickel, and George Gryc (1–63) describes the Chandler River region, which adjoins Naval Petroleum Reserve No. 4 in northern Alaska. Four of the main anticlines mapped show closure, and the 10 formations mapped, which have a total thickness of 16,300 feet, include many beds of subbituminous to bituminous coal.

Application of gravity studies to fluid reservoirs

A study by T. H. McCulloh indicates that it may be possible to use detailed gravity observations to estimate the oil and gas content of porous rocks under favorable circumstances. Porous rocks saturated with petroleum or natural gas differ in bulk density from identical rocks saturated with relatively denser interstitial water by amounts ranging from 0.03 g/cm^3 or more in rocks of 10-percent porosity to 0.11 g/cm^3 or more in rocks of 30-percent porosity.

Organic geochemical investigations

Preliminary analyses by V. E. Swanson and J. G. Palacas of recent sand cemented with organic material, which is present at many places at or near the shoreline of bays and sounds along the Gulf of Mexico coast of the Florida panhandle, indicate that the water-transported organic material consists of 3 major fractions: about 81 percent humate, 15 percent "fulvic acid," and 4 percent hydrocarbons. The hydrocarbons, which have been further fractionated into paraffinic, aromatic, and possibly asphaltic groups, may have been transported with the humic acids that coagulated to form the humate, or they may have been derived from the humate through chemical or biochemical reactions.

Similar organic geochemical studies are currently underway on a suite of bottom-sediment cores from lake, river, bayou, swamp, and bay environments in the Choctawhatchee Bay area of north Florida; and on segments of cores of deep-sea sediment from the north Pacific Ocean, which were provided by G. W. Moore from the U.S. Coast and Geodetic Survey's 1961 *Pioneer* cruise.

OIL SHALE

With recent revived interest in exploitation of the oil shale in Colorado, Utah, and Wyoming, the need for more detailed resources estimates has increased. These estimates are based largely on precise mapping and determination of the extent and thickness of rich oil-shale units by Geologic Division personnel, who also integrate data on cores and cuttings obtained from petroleum companies and the oil-yield analytical data provided by the U.S. Bureau of Mines to obtain the new estimates.

New revised estimates of oil-shale resources have been made by D. C. Duncan and J. R. Donnell for a 1,350-square-mile area in the Piceance Creek Basin, Rio Blanco and Garfield Counties, Colo. Oil shale in this area assaying 5 or more gallons of oil per ton of shale will yield about 1.4 trillion barrels of oil. About 420 billion barrels of oil can be produced from shale units 15 to 540 feet thick that assay 25 to 65 gallons per ton, and 800 billion barrels of oil can be produced from shale units 15 to 1,000 feet that assay 10 to 25 gallons per ton and are interbedded with or lie marginal to the richer shale. Two additional estimates, which consider other factors of economic significance, are that about 100 billion barrels of oil could be produced from 25 to 65 gallon-per-ton shale lying less than 1,000 below the surface; and that about 680 billion barrels of oil could be produced from interbedded rich and lean oil-shale units that would have an average yield of 25 gallons of oil per ton.

In his study in the Firehole Basin quadrangle, Sweetwater County, Wyo., W. C. Culbertson has found that the upper 800 feet of the fluviatile Wasatch Formation of Eocene age contains several lacustrine tongues

[24] H. J. Hyden, 1963, Geologic map of Cooper Cove and Dutton Creek oil fields and vicinity, Albany and Carbon Counties, Wyoming: U.S. Geol. Survey open-file rept.

consisting of oil shale and an underlying thin limestone with a fresh-water fauna. These tongues thicken and become more numerous southward, indicating that in Wasatch time a lake or lakes existed near the Wyoming-Utah border that periodically increased in size. Some of the tongues overlie coal beds, suggesting that the lake transgressed northward across a swamp, first depositing calcareous muds on a peat deposit, then becoming deeper with a stagnant hypolimnion that allowed accumulation of oil shale.

W. B. Cashion (chapter D) has computed the potential oil content of kerogene-rich strata in the Green River Formation of the Uinta basin, Utah-Colorado, from samples from 40 core holes, 110 exploratory wells, and 25 surface localities. He estimates that a sequence of rocks 15 feet or more thick that yields an average of 15 gallons per ton contains about 321 billion barrels of oil. This resource occurs in an area of about 3,000 square miles and is of prime importance as a potential source of synthetic liquid fuel.

WATER RESOURCES

The U.S. Geological Survey investigates the occurrence, availability, and quality of surface and underground waters and the sediment discharge of streams. An extensive hydrologic network of stream-gaging stations, observation wells, and water-quality sampling stations throughout the country provides continuing basic data. Compilations of these basic data are published in the following U.S. Geological Survey Water-Supply Paper series:

"Surface Water Supply of the United States,"

"Ground-Water Levels in the United States,"

"Quality of Surface Water of the United States."

The surface-water records are published at 5-year intervals in 14 numbered parts determined by drainage basins, for the 48 conterminous States, plus 2 additional reports for Alaska and Hawaii. The groundwater records are published in 6 parts representing geographical sections of the country. One part is published each year; 2 parts being published every fifth year. The records of quality of surface water are published annually. In addition, nationwide reports which describe flood frequency at selected gaging stations and extend the data to ungaged sites on major and minor streams are being published in the Water-Supply Paper series in several parts that correspond to the drainage-basin subdivisions of "Surface Water Supply of the United States."

Areal investigations of water resources are made largely in cooperation with State, local, or Federal agencies listed on page A221. These studies include the various aspects of the gelogic and hydrologic environment that relate to the occurrence and movement of water on the surface and underground. Such studies of water resources stress the evaluation of sources of supply, chemical and physical composition, computation of the quantity available for use, description of the direction and rate of movement, evaluation of fluctuations in flow, and determination of disposition of the supply as use, waste, or outflow.

Diversified water-resources investigations are in progress in nearly every State. These fall into two general categories, "area" and "systems" studies. Area studies cover investigations of specific hydrologic problems within an area, generally comprising a political subdivision—the problems of a municipality, a county, or a State. Systems studies, on the other hand, are investigations of the hydrologic environment of natural units such as a river basin or isolated valley or a major aquifer, whose area may include a number of political subdivisions. The purpose of these investigations is to determine the effect on the hydrologic system of changes in any part of it; for example, to predict how use of ground water in one municipality may influence streamflow in another part of a river system.

Investigations stressing the economic aspects of water as a resource are treated in the following section under four areas (fig. 3), which correspond to the administrative subdivisions of the Water Resources Division.

WATER USE

Development and use of water in the United States have rapidly increased with the Nation's growing population and expanding economy. However, because water supplies are limited in some parts of the country a less rapid increase in average per capita water use is expected in future years. The per capita withdrawal use of water in 1960, 1,500 gallons per day (MacKichan and Kammerer [25]), is estimated to have increased to 1,675 gpd in 1964. Future increases are estimated at about 80 percent of the projection of withdrawals, made by the Senate Select Committee [26] which was based on the assumption that optimum amounts of water for irrigation are made available. In 3 of the past 4 years, streamflow as reported monthly by the Geological Survey's "Water Resources Review" was either in the deficient range or well below median in most of the West, excepting the extreme Northwest. The exception was 1962, when streamflow was generally near median and was excessive in limited areas. It is estimated that the average per capita withdrawal demand will increase at the rate of about 0.77 percent per year.

To meet the increasing demand for information for water management, the U.S. Geological Survey investigates and prepares reports on water resources. Many

[25] K. A. MacKichan and J. C. Kammerer, 1961, Estimated use of water in the United States, 1960: U.S. Geol. Survey Circ. 456.

[26] U.S. Congress, Senate Committee on National Water Resources, 1961, National water resources: U.S. 87th Cong., 1st sess., Rept. 29.

of the area studies include some incidental information on water use, particularly those that report on pumpage from wells, which is usually a measure of withdrawal use. Other studies are more specifically concerned with water use, such as studies of specific industries, metropolitan areas, and States. In those studies, water use is determined in relation to time, population, area, unit of product, or the supply of water.

Water requirements of the iron and steel industry

Twenty-five steel plants with a combined production of 37 million tons of steel ingots per year—about 30 percent of the total United States steel production for 1956—withdrew 4 billion gallons of water per day, according to L. E. Otts and F. B. Walling. About 93 percent of this intake was used for cooling. Reuse of water varied from 1 to 45 times in steel-processing plants (plants that begin with pig iron or scrap) and from 1 to 19 times in integrated steel plants (plants that begin with iron ore). About 97 percent of the water intake was from surface-water sources, 1 percent from ground water, and 2 percent from reclaimed sewage. The industry supplied about 93 percent of its own water needs.

The amount of water withdrawn (intake) by integrated steel plants ranged from 1,530 to 70,300 gallons per ton of steel ingot, with an average intake of 29,800 gallons per ton. Water use (intake plus reused water) by these same plants ranged from 11,200 to 110,000 gallons per ton of steel ingot, with an average of 39,800 gallons per ton. Some of this variation is caused by the inclusion of water used for power production and coke production and by differences in products and operation of the plants.

In the 25 plants surveyed, average water use for blast furnaces (20,100 gallons per ton for pig iron) was much greater than that of other processes. But, large quantities of water were also used for open-hearth furnaces (4,990 gallons per ton of steel ingot), electric furnaces (3,210 gallons per ton of steel ingot), and primary rolling mills (3,880 gallons per ton of semifinished steel—blooms, billets, and slabs). Byproduct coking plants used an average of 5,850 gallons per ton of coke.

Chemical quality of public water supplies

Eight maps showing Statewide average dissolved-solids, sodium, and fluoride content and hardness in raw and finished public water supplies of the 50 States, the

FIGURE 3.—Index map of the United States, showing areal subdivisions used in discussion of water resources.

District of Columbia, and Puerto Rico have been prepared by C. N. Durfor and Edith Becker.[27]

The data were derived from 1,596 water systems that serve a total of 103 million people, or 81 percent of the urban population and about 57 percent of the total population.

This survey showed that in 1962, 29 million people used water containing 100 parts per million or less of dissolved solids, 72 million people used water containing 250 ppm or less of dissolved solids, and 89 million people used water containing less than 500 ppm of dissolved solids.

Hardness of public water supplies ranges from less than 60 ppm along the East Coast and far Northwest to more than several hundred parts per million in the midwestern and western States. About 80 percent of the population surveyed used water having a hardness of 180 ppm or less.

Most States east of the Mississippi and several States west of the Mississippi have an average sodium content of less than 20 ppm in finished water supplies. This amount is low enough to be ignored in planning sodium-restricted diets; however, in some water supplies the sodium content is high enough so that it must be considered in planning such diets.

Water containing between 0.6 and 1.7 ppm of fluoride is used by 43 million people. This figure does not include New York City (more than 8 million people), which decided to fluoride its water supplies after the data for this project were compiled.

Nitrate content was calculated but not mapped because about 86 percent of the raw and finished water supplies surveyed contained less than 10 ppm of nitrate, well below the acceptable limit of 45 ppm in drinking water.[28]

ATLANTIC COAST AREA

With the exception of major floods, the waters of the Atlantic Coast States are no longer surplus to the needs of the Eastern States' economy and social pattern. Waters not required for public supply, industry, and agriculture are now in good part utilized for recreation and for the dilution and transport of pollutants.

In the populous East, man is having an increasing effect upon the utility of natural water sources. Even the precipitation that recharges streams and aquifers has been found to have significant quantities of dissolved minerals picked up in passing through the atmosphere of industrialized areas. This requires increasing attention by the hydrologist to the content as well as the amount of available rainfall.

Man's desire for optimum quality of water for each of its many uses has made him sensitive to water characteristics, such as sediment content, which his forebears once accepted without question. A standard feature of many water investigations is the study of the points of origin and patterns of deposition of fluvial sediments produced by natural erosion and carried by floodwaters. Land use is seen as a major factor in sediment production.

The water resources of estuarine areas are moving into a position of greater importance. Water problems, particularly along heavily industrialized and populated estuaries, are critical in number and magnitude. Greater competence in determining the volume and nature of tidal flows has given a better base for the study of water quality and deposition of solid pollutants.

New areas in which large ground-water supplies may be developed were discovered during the year. Additional knowledge of the manner and extent of recharge to ground-water reservoirs was reported upon and will provide a better base for conservation and utilization and perhaps eventual artificial recharge of the resource.

The following project studies for which specific findings are reported indicate that more and more investigations are designed around specific local water problems.

NEW ENGLAND

Ground water in Massachusetts

Studies in the Assabet River basin by S. J. Pollock indicate several areas that are potential sources of large supplies of ground water. The areas are underlain by Pleistocene glaciofluvial deposits and appear to cover about 5 percent of the 175-square-mile basin.

Investigations in the Merrimack River basin in Essex County by J. E. Cotton show that the most favorable aquifers are glaciofluvial sands and gravels in areas where some recharge can be supplied by lakes, streams, or swamps. Ground-water supplies for most uses would require treatment because of pollution in the Merrimack River, which partly recharges the aquifer.

As part of a study of the water resources of the Housatonic River basin by R. F. Norvitch, preliminary information obtained by test drilling suggests that the materials underlying the main valley below Pittsfield are mostly fine grained, indicating that large yields of ground water cannot be expected. Expected yields from bedrock also may be low as indicated by low-flow stream measurements, which suggest that the bedrock is poorly permeable. However, large volumes of water may be obtained locally from bedrock wells that penetrate fault zones.

[27] C. N. Durfor and Edith Becker, 1964, Chemical quality of public water supplies of the United States and Puerto Rico, 1962; U.S. Geol. Survey Hydrol. Inv. Atlas HA 200. [In press]

[28] U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pub. 1956.

Greater Boston area, Massachusetts

The water resources of the 551–square-mile greater Boston area, with about 2.3 million population, were appraised by H. N. Halberg, J. A. Shaughnessy, and G. K. Wood. Of 418 million gallons per day of fresh water used in 1958, 34 mgd was ground water, and 384 mgd was surface water of which 206 mgd was imported from central Massachusetts. Public-supply systems furnished 279 mgd of which about 150 mgd was for domestic use, and the remainder for industrial, commercial, and public supply. Industries and commercial establishments supplied 139 mgd for their own use from private systems. About 1,300 mgd of salt water is used for cooling purposes, mostly in the production of thermal-electric power. The quality of the water from most of the streams and the more than 100 lakes, ponds, and reservoirs in the area is good to excellent for most purposes. The waters are generally soft and their dissolved-solids content is low. Water in streams has higher iron content and color than the ponded water. Yields from wells in sand and gravel range from a few gallons per minute to 1,700 gpm, the water being generally good to excellent. The yield of wells tapping sedimentary rocks averages about 40 gpm and the yield of those tapping crystalline rocks about 20 gpm, the water being generally satisfactory.

Rhode Island

W. B. Allen, G. W. Hahn, and C. R. Tuttle (1–63) found that large increases in the use of water are feasible in the upper Pawcatuck River basin in southern Rhode Island. In 1959, the average use of water was about 1.5 mgd, nearly all of which was ground water. They estimate that as much as 18 mgd of ground water is available in the basin. Generally, the chemical quality of ground water is good except for locally excessive manganese, iron, and nitrate content.

The chief source of fresh ground water of Block Island is a perched aquifer in the southern part of the island, according to A. J. Hanson, Jr., and G. R. Schiner. The aquifer is composed chiefly of sorted glacial deposits of sand and gravel less than 200 feet thick. Generally the water is of good quality but locally may be corrosive or contain excessive iron. With proper development, the aquifer will yield more than 1 mgd.

Quinebaug River basin, Connecticut

M. P. Thomas and A. D. Randall report that quantitative studies in the Quinebaug River basin in eastern Connecticut have emphasized the importance of the stratified glacial drift as a ground-water reservoir. Preliminary estimates indicate that during the moderately dry 1963 water year, ground-water recharge was about 8 inches in areas of till-covered upland and about 20 to 24 inches in areas of stratified drift. Regional flow-duration curves for the period 1931–60 show that the discharge per square mile for a stream draining a basin underlain by till exceeds that for a stream draining a basin underlain by stratified drift only about 10 percent of the time; furthermore, the 95-percent-duration discharge per square mile from a basin underlain by stratified drift is about 30 times more than that from a basin underlain by till. In this region, the 95-percent-duration flow is about the same as the median annual 7-day low flow.

Chemical quality of water in the Quinebaug River basin is generally good, according to C. E. Thomas, Jr. Only 5 percent of the ground-water samples analyzed had a hardness greater than 120 parts per million. However, dissolved iron and manganese in concentrations as high as 3.7 ppm and 5.7 ppm, respectively, are a problem locally.

Precipitation containing sulfate ions, presumably originating from smoke, is the major source of sulfate over nearly half the basin. In other areas the mineral content of water is increased by solution of sulfide minerals from the bedrock and by industrial wastes discharged into some streams. Calcium, bicarbonate, and sulfate are the principal ions in precipitation from storms approaching the basin from the west or north.

Waterbury-Bristol area, Connecticut

The water resources of the Waterbury-Bristol area have been appraised by R. V. Cushman, F. H. Pauszek, A. D. Randall, and M. P. Thomas. Nearly 170,000 people live in this highly industrialized area. The principal sources of water are the Naugatuck and Pequabuck Rivers and their tributaries, and ground water. Municipal water supplies are obtained from tributary streams, and rural supplies from wells. The chemical quality of the water in the Naugatuck River during low flows fluctuates erratically; extremes in pH of 4.5 to 9.1 have been observed, sulfphate concentrations have ranged as high as 93 parts per million, and iron concentrations as high as 1.8 ppm. The variations in quality and the high concentrations of individual constituents are attributed to industrial wastes, especially from brass and copper mills. Additional large water supplies are available from streams, but at present, pollution limits their use. Moderate supplies are available from ground water contained in sand and gravel.

NEW YORK

Comparison of high and low flows of streams

The ratio of very high discharge to very low discharge for most unregulated streams draining more than 100 square miles in New York State is between

100-to-1 and 300-to-1, based on a statewide appraisal study of existing records by J. C. Kammerer in 1963. A major exception is the upstream part of the Schoharie Creek basin for which the ratio is more than 2,500-to-1, based on measurements at Prattsville, where the creek drains an area of 236 square miles. The high ratio results from this Catskill Mountain area being subject to intense storms and its soil and rocks having very limited infiltration rates and storage.

The high streamflow factor used in this comparative analysis was the discharge of the once-in-50-year flood, and the low-flow factor was the minimum 7-day discharge with a recurrence interval of once in 10 years. Many streams draining small areas probably have ratios greater than 300-to-1. On the other hand, small streams on Long Island have low ratios because most of the flow consists of ground-water discharge. Therefore, peak discharges are lower on Long Island than elsewhere in the State, and minimum discharges are higher than average.

Sources of ground water in Jamestown area

Studies by L. J. Crain (1–63) in the Jamestown area show that recharge to a sand and gravel aquifer confined by dense clays is by infiltration from tributary streams in a glaciated bedrock valley. The streams drain till-covered bedrock hills and cross alluvial deltas which have been deposited outward into the valley at many places. These deposits connect with the deeper aquifer and serve as storage reservoirs for the aquifer. The city of Jamestown pumps 6 mgd from the aquifer. Water levels in wells near the apex of the alluvial deltas fluctuate as much as 40 feet annually. Tributary streams flow only following periods of heavy precipitation because most of the runoff from the adjacent highlands infiltrates to the aquifer. Discharge measurements indicate that the main-stem stream in the valley does not lose an appreciable amount of water to ground-water recharge.

Ground water in lower Oswego River basin

An investigation by I. H. Kantrowitz and J. A. Tannenbaum in the area lying roughly between the eastern Finger Lakes and the Tug Hill plateau is focused on locating sources of large supplies of ground water and on studying the occurrence of salty water. Preliminary findings indicate that potential sources of large supplies may be restricted to sand and gravel deposits in the northern ends of glaciated valleys in the Appalachian Plateaus and in the adjacent parts of the Mohawk-Ontario lowland.

Salty water occurs in bedrock underlying some of the glaciated valleys, and in parts of the Mohawk-Ontario lowland that are farther from the Appalachian Plateaus. In some of these areas, the salty water has migrated upward into the overlying glacial deposits.

Water resources of Syracuse area

The water resources of the Syracuse area have been appraised by H. N. Halberg, O. P. Hunt, and J. A. Shaughnessy. Water is plentiful from streams and lakes and aquifers but it is not in all ways of the quality desired. In 1956 about 29 percent of the 198 million gallons per day of water used for all purposes was drawn from public-supply systems, about 1 percent from private domestic systems, and the remainder from self-supplied industrial systems. Much ground water is available from the sand and gravel of the Onondaga Creek basin, from stratified glacial deposits along the present streams, and in buried valleys. But, by the year 2000, the demands on public supplies are expected to be double their present capacity, and nearby lakes and rivers will have to be used to supplement ground-water sources.

Water-level decline in Nassau County

Water levels in the principal aquifer in west-central Nassau County have declined as much as 11 feet since 1953 as a result of heavy pumping, according to John Isbister.

NEW JERSEY

Water-quality characteristics of streams

J. R. George and P. W. Anderson (1–63) have studied the interrelation between water quality and several environmental causative factors as part of a reconnaissance study of the chemical, physical, and bacteriological water-quality characteristics of New Jersey streams. The relations between most water-quality parameters and streamflow normally were found to be inverse. However, direct relations were found between dissolved-solids content and streamflow for several streams in the outer Atlantic Coastal Plain.

The prevalent chemical character of streams in relation to geologic terrane was studied. Streams draining glacial-drift deposits in the Valley and Ridge province were shown to have a low dissolved-solids content, ranging from 30 to 90 parts per million. Streams draining limestone and dolomite deposits were found to have high concentrations of calcium, magnesium, and bicarbonate and a correspondingly high dissolved-solids content, ranging from 90 to 250 ppm. The predominant anion found in streams draining Triassic sediments was sulfate. Streams draining the Coastal Plain were found to have an extremely low dissolved-solids content, ranging from 20 to 60 ppm.

Streams draining the highly industrial and urban areas generally were found to reflect the influence of waste-water discharges. The highest values of dissolved solids, synthetic detergents, turbidity, and coliform

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bacteria were found in streams draining these areas. Streams draining farmlands also tended to have high values of turbidity and coliform bacteria.

Ground water in Camden County

Large amounts of ground water are available from various aquifers in Camden County, according to Ellis Donsky (1-63). Most domestic and other small supplies can be obtained from wells less than 250 feet deep. Most moderate to large yields for industrial and public supplies can be obtained from properly developed wells at depths of 1,000 feet or less. Yields of up to 1,500 gallons per minute are obtained from properly spaced wells in the Raritan and Magothy Formations within 2,000 feet of the Delaware River. Elsewhere, yields of up to 1,000 gpm generally can be obtained from the Raritan and Magothy Formations.

Small to moderate supplies are obtained also from other formations in the county. Yields up to 600 gpm are obtained from the Wenonah Formation, Mount Laurel Sand, and Cohansey Sand. Smaller yields, up to 100 gpm, are obtained from the Englishtown, Vincentown, and Kirkwood Formations.

The chemical quality of the water from the various aquifers is suitable for most uses; however, some of the constituents may be objectionable for certain purposes.

PENNSYLVANIA

Low flows and annual yield of streams

A new minimum-runoff map for Pennsylvania, prepared by W. F. Busch and L. C. Shaw and based on all gaging-station records in the State with 5 years or more of record, shows the average 7-day minimum flows having a 2-year recurrence interval. On this map the State was subdivided into three classifications on the basis of flow: less than 0.1 cubic feet per square mile, 0.1 to 0.2 cfs per sq mi, and more than 0.2 cfs per sq mi. Numerous minor changes distinguish this map from a previous map compiled from available data for a lesser number of long-term gaging stations.

An annual stream-yield map for Pennsylvania was also prepared. Average discharges for all years of record available at each gaging station were used to subdivide the State into three classifications of runoff: less than 20 inches, 20 to 25 inches, and more than 25 inches.

These maps show that there is no correlation between minimum runoff and annual yield. Streams with high average annual yields do not necessarily have well-sustained low flows and, conversely, some streams with low yields have well-sustained low flows.

The average 7-day minimum varies from no flows at a few gaging stations to a maximum of 0.56 cfs per sq mi at Yellow Breeches Creek near Camp Hill. Sixty percent of the gaging stations have a sustained flow of more than 0.1 cfs per sq mi for the 7-day minimum.

Sediment content of Schuylkill and Susquehanna Rivers

Preliminary appraisal of the quality of surface and ground waters of the Schuylkill River basin by J. E. Biesecker, J. B. Lescinsky, and C. R. Wood indicates a significant decrease in suspended-sediment yields from the upper basin between 1948 and 1960. Observations of chemical quality for the same period show no substantial change in the water chemistry. A primary objective of the study is evaluation of the effects of the Schuylkill River Restoration Project, 1950. Initial trap efficiency of three headwater desilting basins constructed during the restoration project was about 90 percent.

Preliminary findings by K. F. Williams as part of a comprehensive interagency water-resources study of the Susquehanna River basin indicate that average annual sediment yields from selected subbasins range from 50 to 500 tons per square mile.

Quality of water in Lehigh River

The water of tributaries in the Lehigh River basin has been mapped into three general types on the basis of prevalent dissolved-solids content and predominant ions in solution, according to P. W. Anderson and L. T. McCarthy, Jr. (2-63) and W. B. Keighton. Most of the streams in the basin have a very low dissolved-solids content, 20 to 40 parts per million; are slightly acidic, pH 4.5 to 7.0; and contain calcium, bicarbonate, and sulfate as the predominant ions. However, several tributary streams draining the Middle Anthracite coal fields in the western portion of the basin contain much greater concentrations of dissolved solids, 100 to 500 ppm; are more acidic, pH 2.0 to 4.0; and contain calcium and sulfate as the predominant ions. Other tributary streams, draining extensive Cambrian and Ordovician limestone and dolomite beds in the southern portion of the basin, also have a high dissolved-solids content, 100 to 250 ppm, but contain calcium and bicarbonate as the predominant ions and are usually basic, pH 6.5 to 8.0.

The studies show that each of these three water types influences the water chemistry of the main stem. The upper reaches of the Lehigh River have a low dissolved-solids content, are slightly acidic, and contain calcium, bicarbonate, and sulfate as the predominant ions. Below the confluence with streams draining the coal fields, the dissolved-solids content increases two to three fold; the calcium and sulfate content also increases, with a corresponding decrease in bicarbonate content; and the pH decreases slightly. Streams draining the southern part of the basin tend to neutralize the effects of these acidic tributaries, thereby increasing the bicarbonate-ion content and the pH value of the main stem.

Monongahela River basin

According to G. W. Whetstone, the overall water assets of the Monongahela River basin are good and in large measure untapped. Outflow from the basin averages about 12,500 cubic feet per second, or about 8,100 million gallons per day, at Braddock, Pa. For perspective, this is about three times the amount of water presently utilized by the municipal and industrial supply of the Pittsburgh area. Supplies of ground water for commercial, agricultural, and industrial use are available in parts of the basin, and with some local exceptions, adequate domestic well supplies are generally available.

The major problem in relation to optimum water-resource-development is acid mine drainage. The Monongahela River receives more acid than it is capable of neutralizing. Long-term water quality and streamflow measurements show that the Monongahela River carries 200,000 tons of sulfuric acid per year into the Ohio River at Pittsburgh. The larger tributary streams to the Monongahela River contribute only 30 percent of the mineral acidity to the main stem. The principal sources of the mineral acid reaching the Monongahela River are the numerous small tributary streams in the reach between Clarksburg, W. Va., and Pittsburgh, Pa.

Ground-water supplies in Lancaster, Chester, and Delaware Counties

Short-term pumping tests in 250 wells in the Cambrian and Ordovician carbonate rocks of Lancaster County indicate that these rocks are poorer aquifers than rocks of the same age in the Lebanon Valley, 5 miles farther north. Harold Meisler (1–63) and A. E. Becher report that 42 percent of the wells in the Lebanon Valley yielded as much as 10 gallons per minute per foot of drawdown, but in Lancaster County only 16 percent of the wells yielded that much. The tests showed that 25 percent of the wells in the Lebanon Valley and 52 percent of the wells in Lancaster County yielded less than 1 gpm per foot of drawdown. The two areas are similar in lithology and structure even though they are separated by a narrow ridge of Triassic sedimentary rocks.

Preliminary findings in a ground-water investigation in Chester and Delaware Counties by C.W. Poth indicate that most wells yield 25 gpm or less, but much larger yields have been obtained. Maximum yields found were 204 gpm in the Baltimore Gneiss, 350 gpm in the Wissahickon Formation, and 100 gpm from a well in gabbro. The highest yield was 650 gpm from the Cambrian Vintage Dolomite.

MARYLAND

Quality of water in Lower Potomac-Chesapeake Bay area

Because of an extended dry period, monthly sediment loads measured in the Potomac River basin during the summer of 1963 are believed to be the lowest in many years, according to F. J. Keller. Although the annual sediment load of the Potomac River at Point of Rocks was about normal (1.1 million tons), the average monthly load for July, August, and September was only 1,060 tons. Total load for the 3-month period amounted to less than 1 percent of annual load, whereas during March 89 percent was transported.

A reconnaissance study by J. D. Thomas of the chemical quality of water in the Monocacy River basin in Maryland indicates water of the calcium bicarbonate type. The hardness ranged from 4 to 142 parts per million and the dissolved-solids content ranged from 19 to 187 ppm. Several towns and communities use the streams for the disposal of sewage, which is the main source of pollution in the basin.

Concentration of several minor elements in the Patuxent River in Maryland is approximately the same as the median values for these elements in the largest rivers of North America. S. G. Heidel reports the following average results, in milligrams per liter, for the Patuxent River at Hardesty, Md. (median values for the largest North American rivers are given in parentheses for purposes of comparison): strontium 0.034 (0.060), boron 0.044 (0.010), rubidium 0.0075 (0.0015), lithium 0.0008 (0.001), copper 0.0055 (0.0053), lead 0.004 (0.004), and nickel 0.0105 (0.0100). Measurable quantities of more than 17 minor elements were determined spectrographically, but only the concentrations of rubidium were consistently higher at several stations in the Patuxent River basin than those determined in the principal rivers of the United States and Canada.

Water resources of Gunpowder Falls basin

The total water resource of the Gunpowder Falls basin was studied by Deric O'Bryan and R. L. McAvoy with regard to its past, present, and probable future uses. Quantitative estimates indicate that about 80 percent of the runoff could be retained in the existing reservoirs, if needed, and diverted to the water-supply system of metropolitan Baltimore. The safe yield of 148 million gallons per day, computed by the City of Baltimore Bureau of Water Supply, is very conservative; queuing-theory application shows that a higher draft rate of 175 mgd would result in a deficiency only once in 100 years; 220 mgd, once in 10 years.

Water supply is the first and established major use of the resource. Rapidly increasing pressures, which often are incompatible with water-supply management and with each other, are (1) expanding suburbanization of sections of the basin, and (2) development of the basin's potential for recreational needs.

Use of ground water in Salisbury area

E. G. Otton reports that a nearly completed inventory of all large-capacity wells in the Salisbury area indicates increasing use of ground water for supplemental irrigation of crops. Most of the irrigation wells have been installed within the past 10 years. Recent well data indicate a major gravel-filled post-Miocene valley between Salisbury and the Delaware State line. This buried valley, nearly 200 feet deep in places, contains large untapped reserves of potable ground water.

WEST VIRGINIA

Ground water in Monongahela River basin

Ground-water investigations by Gerald Meyer and B. M. Wilmoth in the Monongahela River basin suggest that pressure gradients probably extend downward through the knobby hills, which characterize the topography of the basin, to nearby streams and to the main body of ground water in rocks beneath the hills. Wells drilled successively deeper in the hills commonly have successively lower water levels. However, owing to horizontal stratification and alternation of beds of low transmissibility with beds of higher transmissibility, large amounts of water are shunted laterally to nearby hillside outcrops. Coal-mine drifts through the hills, acting as collectors, intercept part of the ground water and accelerate its discharge.

Low flows in West Virginia streams

Low-flow investigations in West Virginia indicate that the median annual 7-day minimum flows range from 0.1 to 0.2 cubic feet per second in parts of the Potomac and Monongahela River basins, and below 0.1 cfs elsewhere, according to E. A. Friel. The subbasins having the higher runoff are the South Branch Potomac River, Opequon Creek, and upper Cheat River basins.

NORTH CAROLINA

Quality of ground water in western North Carolina

Findings by R. L. Laney in a geochemical investigation of western North Carolina show that ground water in this area is of good quality and generally contains less than 70 parts per million dissolved solids. Seventy percent of the water sampled from springs contained less than 30 ppm dissolved solids. In some localized areas, water contains more than 0.3 ppm iron. Relatively high concentrations of fluoride (0.2 to 1.3 ppm) were found in ground water in the northeastern half of the area. Ground water was classified into five general types on the basis of chemical analyses. The types are related to the rocks in the area.

Rainwater in western North Carolina has a calcium sulfate-bicarbonate composition and generally contains less than 0.2 ppm silica and 10 ppm dissolved solids.

GEORGIA

Water resources of Georgia

The water resources of Georgia have been appraised by J. T. Callahan, L. E. Newcomb, and J. W. Geurin. The average runoff from the State is about 39,000 million gallons per day. The largest use of water is for hydroelectric power, and averages 41,000 mgd. This exceeds the average supply because water for power is used many times, 13 times on the Cattahoochee River and 10 times on the Savannah River. Industrial use averages 2,130 mgd, mostly for steam-electric power. Public water supplies use 370 mgd, mostly from streams in northern Georgia and from wells in the Coastal Plain of southern Georgia. Rural supplies use about 91 mgd, and irrigation only 37 mgd.

Base flows of streams in the Coastal Plain

Much of the low flow in parts of the Coastal Plain in Georgia makes its first appearance as surface flow directly in or very near the channels of the major streams, according to A. N. Cameron and R. F. Carter. The inflow per square mile of surface drainage area for segments of the Ocmulgee, Altamaha, Chattachoochee, and Flint Rivers is many times as large as that for the small tributary streams that enter the major streams in the same segments. During low-flow periods the increments in flow range up to 1,200 cubic feet per second from increments of drainage areas of only 1,000 to 2,000 square miles.

Ground water in Glynn County

The transmissibility of the principal artesian aquifer in Glynn County, as determined by D. O. Gregg from aquifer tests, ranges from about 480,000 to about 2,000,000 gallons per day per foot. An average transmissibility of about 1,100,000 gpd per foot was computed by analysis of piezometric maps. Preliminary data indicate that the relatively low transmissibility of the aquifer that underlies the south-central part of Glynn County may be responsible for steep hydraulic gradients in the southern part of the Brunswick Peninsula and in the Jointer and Colonel Islands area.

At Brunswick an increase in water use of 30 million gallons per day in late 1962 caused a marked decline of water levels. These ranged from about 20 feet near the center of pumpage, 3 to 4 feet 13 miles northwest and west, 6 to 7 feet 10 miles eastward, and 1 to 2 feet 10 miles southeastward, according to R. L. Wait.

Ground water in southwestern Georgia

The Dougherty Plain region in Seminole and Decatur Counties, southwestern Georgia, has been shown by C. W. Sever to be one of the most favorable ground-water regions in the United States. In this region, a shallow limestone aquifer is capable of yielding an estimated 20 to 40 million gallons per day to properly developed well fields and is capable of a sustained yield of several hundred million gallons per day within the two-country area.

Water resources of Atlanta Metropolitan Area

Power operations on the Chattahoochee River at Buford Dam and the reregulation of power waves at Morgan Falls Dam are the principal factors affecting the occurrence of the main water resource in the Atlanta metropolitan area, according to M. T. Thomson and R. F. Carter. During the 1963 water year, 100 percent of the water passing Buford Dam was used for power generation. Peak power on Mondays through Fridays used about 82 percent of the flow. The remaining 18 percent was used for offpeak power during nights and weekends.

The five power waves per week would pass Atlanta at night and be wasted if they were not reregulated at Morgan Falls Dam. The reregulation is intended to provide 750 cubic feet per second at all times at Atlanta to satisfy minimum water-supply and industrial needs with peak flows for dilution of sewage during each afternoon to match the pattern of sewage discharge. The desired daily flows, in cubic feet per second, for Saturdays, Sundays, Mondays, and the Tuesday-to-Friday periods, and the duration-curve data for natural conditions before regulation began and for the 1963 water year after reregulation began are shown by the following table:

Day	Desired flow		Percent of time the desired flow was equalled or exceeded			
			Daily		Peak	
	Daily	Peak	Natural	1963	Natural	1963
Saturday	1, 150	2, 000	75	83	43	70
Sunday	1, 000	1, 500	80	65	60	40
Monday	1, 340	2, 000	66	68	43	55
Tuesday–Friday	1, 510	2, 500	59	76	31	70

The table shows a great increase in the flows available for sewage dilution Tuesdays to Saturdays, which would have been even more impressive if the releases from Buford Dam had not been severely reduced for 3 months during the winter. The reregulation on Sundays has not been so effective because depletion of the channel storage between Morgan Falls Dam and Atlanta causes a surplus of water at night, when it is not needed, instead of during the Sunday peaks.

Attenuation of the power waves complicates the analysis of tests by the city for water-quality control. The waves during the periods of low inflows travel at an average rate of 2.7 miles per hour, but the water itself travels at rates of 0.7 to 1.4 miles per hour. Water samples taken where the dissolved-oxygen concentration is believed to be lowest, 37 miles downstream, represent municipal sewage discharged as much as 2 days earlier.

FLORIDA

Solution cavities in Tertiary limestone

The distribution of cavities in the Tertiary limestone and the general decrease in size and numbers with depth and with distance from recharge and discharge areas suggest to V. T. Stringfield that the present pattern of circulation developed chiefly during Pleistocene time when sea level stood both higher and lower than at present. During the lowest level of the sea, the water table in the limestone in north-central Florida may have been as much as several hundred feet below the present level, with deep underground drainage to the sea similar to that at the present time in the limestone in northwestern Jamaica. The solution cavities and caverns were formed chiefly in the upper part of the zone of saturation, which rose and declined with changes in Pleistocene sea level. Vertical shafts or natural wells, some of which are several hundred feet deep, were formed by solution of water moving down along vertical joints in the zone of aeration.

Water atlas of Florida

Maps of Florida that show the distribution of average annual runoff and contain information concerning the most commonly used aquifers have been prepared by W. E. Kenner, W. J. Shampine, and L. W. Hyde as part of a water atlas of Florida.

Runoff throughout most of Florida averages between 10 and 20 inches per year. Southern Florida, however, with large expanses of low wet lands averages less than 10 inches per year. Northwestern Florida, with relatively few lakes and swampy areas and relatively steep valleys has a considerably higher runoff, averaging between 30 and 40 inches.

The Floridan aquifer is the aquifer most commonly tapped for ground-water supplies in Florida. However, in the southern part of the State and along most of the east coast, it contains water with high chloride content, and ground-water supplies are taken from the shallow sand aquifer or, in the Miami area, from the Biscayne aquifer. In extreme northwestern Florida, although water in the Floridan aquifer has a low chloride content, the Floridan is little used as a source of ground water. In this area most ground-water supplies come from a prolific, more easily accessible, sand and gravel aquifer.

Water budget of Green Swamp area

Hydrologic studies by R. W. Pride, F. W. Meyer, and R. N. Cherry of the Green Swamp area in central Florida during the period 1959–61 show that although surface runoff varied through a wide range from wet to dry years, ground-water outflow and evapotranspiration varied little. Water-budget factors for the Green Swamp area show that average rainfall on the area ranged from 70.9 to 34.7 inches, surface runoff ranged from 31.1 to 2.3 inches, ground-water outflow ranged from 1.8 to 2.2 inches, water derived from storage ranged from insignificant amounts to about 4.3 inches, and evapotranspiration losses ranged from 34.5 to 39.1 inches.

Quantitative and qualitative data indicate that recharge to the Floridan aquifer in the Green Swamp area is probably no greater than that in other parts of central Florida, although the highest piezometric levels on the Florida peninsula underlie the southeastern part of the area. Geohydrologic data indicate that the high piezometric levels are caused partly by hydrologic barriers formed by faulting and by solution collapse.

Recharge of principal aquifer in Orange County

The principal recharge area of the Floridan aquifer in Orange County is in the western part of the county and adjoining parts of Lake and Polk Counties. W. F. Lichtler, Warren Anderson, and B. F. Joyner (1–64) delineated the general recharge area by using the shape and slope of the piezometric surface, the relative streamflow from various basins in the county, and a knowledge of the geology of the region.

Water resources of Myakka River basin

The quantity and quality of surface and ground water are highly variable in the Myakka River basin and the adjacent coastal area. Preliminary data collected by B. F. Joyner, Horace Sutcliffe, and J. D. Warren have revealed that potable ground water is available in limited amounts from the Tampa and Hawthorn Formations in the northwestern part of the basin. Large quantities of ground water from the Suwannee and Avon Park Limestones are suitable for irrigation but not for public supplies because the dissolved solids exceed 1,000 parts per million, the sulfate content exceeds 500 ppm, and the hardness exceeds 500 ppm.

All the streams in the basin go dry or recede to very low flows. During low-flow periods, discharge from heavily pumped irrigation wells and some wild flowing wells deteriorates the quality of the surface water. During periods of high runoff, the dissolved-solids content of the water generally is less than 100 ppm. At the beginning of each high-water period, the color index is high, generally greater than 100 color units.

Eocene aquifer system of northeastern Florida

Mapping of water-bearing Eocene limestones in northeastern Florida by G. W. Leve indicated that the Floridan aquifer there is an aquifer system rather than a single hydraulic unit. The system contains at least three permeable zones separated by relatively impermeable dolomite and limestone beds. The most prolific water-bearing zone is in the Lake City Limestone. Deeper zones contain water under higher artesian pressure than the shallower zones; however, tapping these deep zones may result in a more rapid upward intrusion of deep-seated saline water. Present contamination of the shallower artesian zones occurs in a limited area and is from a combination of vertical and lateral intrusion of saline water.

Water supplies of Econfina Creek basin area

A study of the Econfina Creek basin in northwestern Florida by R. H. Musgrove, L. G. Toler, and J. B. Foster indicates that ground-water levels along the Gulf coast have been drawn down as much as 60 feet. This drawdown is caused by heavy pumping by industry, municipalities, and military bases. Econfina Creek and small streams bring a supply of over 700 million gallons per day of good water to this area. This supply is being developed to relieve the excessive draft of ground water.

PUERTO RICO

Chemical character of Río Espíritu Santo

Preliminary studies by Raúl Díaz and Rafael Dacosta of the chemical characteristics of Río Espíritu Santo, which rises in the Luquillo Mountains in northeastern Puerto Rico, indicate that the principal chemical erosion products are silica and calcium carbonate. Somewhat more than 50 percent of the sodium chloride (salt) load transported by the river is a direct contribution from rainfall. Turbidity is extremely low at base and moderate streamflows. Despite the luxuriant, dense vegetative cover, color in the water does not exeed 5 units (Hellige colorimeter–Hazen scale) and is less than 3 units most of the time.

In the upper basin, the total dissolved-solids concentrations are no greater than 40 parts per million, and where the stream enters the coastal plain the dissolved-solids content usually is less than 70 ppm, of which silica comprises almost 30 percent. Hardness does not exceed 50 ppm throughout the basin, and in the main stem of Río Espíritu Santo it usually is less than 25 ppm.

Utilization of Río Loco

In a study of the Río Loco basin, southwestern Puerto Rico, to determine the potential of this predominantly agricultural area for industrial water-supply, N. E. McClymonds concludes that the Río Loco and Loco Reservoir are the keys to obtaining additional water.

On the average, about 8,000 acre-feet of water enters Loco Reservoir annually by natural drainage, and about 80,000 acre-feet enters by diversion from river basins adjoining on the east and north. Of the 88,000 acre-feet total, 18,000 acre-feet is diverted westward for irrigation of Lajas Valley. The remaining 70,000 acre-feet reaches the coastal plain of the Guánica area in irrigation canals (6,000 acre-feet) and in the Río Loco. Wells pump 15,000 acre-feet annually for irrigation from alluvial deposits on the plain. When ground-water levels are low, up to 200 acre-feet of recharge per day can seep from Río Loco into the ground-water system. Since much of the discharge of water from Loco Reservoir occurs in slugs at rates of 100 to 600 cubic feet per second related to hydroelectric operations, a large amount of water is lost to the sea. If this water were released with more uniform distribution during the year, it is estimated that another 15,000 acre-feet could be pumped annually from wells; and more could be obtained directly from Loco Reservoir.

VIRGIN ISLANDS

Test drilling under the supervision of D. G. Jordan and O. J. Cosner indicates that significant quantities of ground water are present on St. Thomas and St. John, U.S. Virgin Islands. Wells having highest yields are developed on the north side of the islands where rainfall is highest, and in guts (valleys) where runoff is concentrated. At present, potable water on these two islands comes from rain catchments, salt-water distillation, or barged supplies from Puerto Rico. The use of local ground water could result in large monetary savings and would give a more stable supply.

During periods of heavy surf on St. John, salt water infiltrates beach sands to form a ground-water mound a few feet inland from the shore. The salt water pollutes fresh water moving seaward through the sand.

The chemical quality of ground water in some wells on St. Croix deteriorates with depth. Water from shallower depths is potable, but from greater depths is brackish.

MIDCONTINENT AREA

The midcontinent area, a water-rich region by comparison with the western part of the United States, has its share of problems associated with increasing development and the maldistribution, in time and place, of the existing water resources. Work of the U.S. Geological Survey is directed toward the resolution of these problems, both present and future, by (1) appraising the available water resources in terms of quantity and quality and locating new and undeveloped water sources, (2) investigating specific problems to provide hydrologically sound guidelines for their solutions, and (3) improving hydrologic knowledge to facilitate water-management practices based on thorough understanding of the hydrologic environment.

In response to an increasing demand for water and water information, the available supply has been appraised in many political and drainage units in the midcontinent States. These investigations indicate a generally abundant water supply and serve as a basis for orderly development of new facilities to meet accelerating public-supply, irrigation, and industrial water demands. In a few such studies, previously unknown ground-water sources have been discovered that add significantly to the available supply. For example, in Winston County, Ala., subsurface geologic studies revealed a previously untapped bedrock aquifer now being developed for municipal supplies. In Iowa, Minnesota, and other north-central States, studies continue to reveal buried bedrock valleys and aquifers of limited areal extent capable of yielding adequate supplies in some otherwise water-deficient areas.

Specific problems of declining ground-water levels, deficient streamflow, and local overdevelopment of water sources have required increasing attention. The need for an alternate and supplemental supply for the city of New Orleans has led to exploration and confirmation of large reserves of ground water in deep aquifers underlying Lake Pontchartrain. In Missouri, expanding industrial activity in the Joplin area aroused increased interest in developing ground-water supplies from abandoned mines. Declining water levels in aquifers in Baton Rouge, La., will present future salt-water encroachment problems than can be resolved by planned development based on recently completed studies in the area. Deficient streamflow recorded in southern Michigan, as elsewhere in the midcontinent States, provides emphasis to the need for water-storage facilities and coordinated use of ground- and surface-water resources.

Knowledge of the hydrologic environment has been furthered by increased emphasis on interrelations of ground and surface waters and the physical factors controlling their movement. Streams and aquifers that are hydraulically connected offer favorable conditions for coordinated use of the total water resource of an area, plus opportunity for artificial or induced ground-water recharge and storage of excess stream runoff. Studies in the glaciated northern part of the midcontinent area show numerous possibilities for improved water development and management practices utilizing these concepts.

MINNESOTA

Aquifers in glacial Lake Agassiz

Prior to pumping tests by R. W. Maclay, T. C. Winter, and G. M. Pike, it was not certain whether adequate ground water for municipal supply could be developed in the water-poor area in the lake plain of glacial Lake Agassiz. Tests near Stephen, Marshall County, show that wells in a shallow aquifer of very fine sand and silt about 50 feet thick can furnish enough water for a town supply. Wells capable of yielding 50 gallons per minute can be constructed by proper screening and sand packing. Beneath the lake plain of glacial Lake Agassiz are many similar aquifers that are potential sources of moderate quantities of ground water.

WISCONSIN

Ground water in central Sand Plains region

Glacial deposits in the Wisconsin River basin are sources of abundant ground water, and development can be increased significantly without seriously affecting water levels or depleting streamflow. Studies by C. L. R. Holt (1–63) in Portage County indicate that wells yielding 1,000 to 2,000 gallons per minute can be developed and ground-water pumpage increased substantially. Declines of water level and lake stages during 1955–60 were caused by deficiency in precipitation rather than irrigation pumpage.

In the lower and central valley of the Wisconsin River, large-capacity wells can be developed in the highly permeable glacial deposits, and the annual rate of ground-water withdrawal is far less than the available supply. An abundant ground-water supply is available from the principal aquifer, which is estimated to be as much as 165 feet thick, according to R. W. Devaul and L. J. Hamilton.

Ground-water potential of bedrock aquifers

R. D. Hutchinson found that ground water of good chemical quality is available in moderate to large quantities from bedrock aquifers in Kenosha and Racine Counties. An important sandstone aquifer yields 1,000 gallons per minute or more to wells, and the Niagara Dolomite locally can yield as much as 500 gpm. In 1963 the total ground-water withdrawal in the 2 counties was about 2 million gallons per day, an amount that can be exceeded greatly without adverse effects.

P. G. Olcott reported that sandstone aquifers of Cambrian and Ordovician age in Winnebago County can be developed much more extensively than at present. In the eastern part of the county, however, a zone containing water with more than 1,700 parts per million dissolved solids and more than 900 ppm sulfate limits ground-water development. In this area, where population and industry are concentrated, surface water is generally a more satisfactory source of supply.

In the Milwaukee-Waukesha area J. H. Green and R. D. Hutchinson (2–64) found that ground-water pumpage from the sandstone aquifer has shifted to the northwest from near downtown Milwaukee. The water level declined about 98 feet in the northwestern part of the area during 1950–61 as a result of this shift.

MICHIGAN

Ground-water basins in Marquette iron range

A study by T. G. Newport in the Marquette iron range area indicates substantial disparities between effective sizes of ground-water drainage basins and surface drainage basins. Water-level observations show that the ground-water divide is about 3 miles west of the topographic divide between the Chocolay and East Branch Escanaba River basins, and that ground water moves eastward from the Chocolay basin into the Escanaba basin. Where large differences in elevations between adjacent topographic basins exist, such disparities in effective size of ground-water basins can generally be expected.

Drought conditions in southern Michigan

Computation of 1963 streamflow records is reported by L. E. Stoimenoff to show that runoff for the 1963 water year in the southern half of the Lower Peninsula was generally the lowest since 1931. New minimum daily mean discharges were reported for many gaging stations, and levels in 5 of 23 lakes that have been gaged for 15 years or more declined to new lows. Lakes Michigan and Huron fell to new lows in January 1964. In December 1963, ground-water levels were at new lows (based on records since the mid-1940's) for the 17th consecutive month in the south-central part of the

Lower Peninsula. Cumulative precipitation deficiency of as much as 19 inches for the past 2 years in southern Michigan is the principal cause of the drought condition. At Lansing the precipitation for 1962 and 1963 was in the lowest decile for the 100-year period beginning in 1864.

OHIO

Sandstone aquifers in northeastern Ohio

A regional study by J. L. Rau of the most important of the bedrock aquifers in northeastern Ohio indicates that small to moderate supplies of ground water may be obtained from the Cussewago Sandstone of Mississippian age and Berea Sandstone of Devonian or Mississippian age. The Cussewago Sandstone yields potable water in parts of Ashtabula, Trumbull, Portage, and Mahoning Counties. The average thickness of the aquifer is about 50 feet, but it exceeds 80 feet in about 30 percent of the area. The Berea Sandstone yields potable water in a 3,500-square-mile area, where its thickness averages about 40 feet. The most promising areas for development of moderate supplies of ground water from one or both of these aquifers are in southern Cuyahoga, Geauga, northern Portage, southeastern Ashtabula, and Trumbull Counties.

Adequate ground water at Lancaster

An investigation by G. D. Dove shows ample ground water to be available from glacial sand and gravel deposits in the Hocking River valley near Lancaster, Fairfield County. This source can be contaminated, however, by substantial increase of ground-water withdrawal and consequent induced recharge, through the highly permeable glacial deposits, of wastes discharged into the Hocking River.

Ground water in Miami River valley

Electric-analog model studies by A. M. Spieker in the Miami River valley indicate that the glacial-outwash aquifer in the Fairfield–New Baltimore area should be able to sustain pumping of at least 80 million gallons per day, or 3 times the present rate of withdrawal. The valley-train aquifer, which is about 2 miles wide and 150 to 200 feet thick, can be recharged by induced infiltration from the Great Miami River along the 15-mile length of the modeled area.

INDIANA

Surface-water supplies in Delaware County

More than 50 base-flow measurements by R. E. Hoggatt in the Mississinewa River basin above Marion and the White River basin above Noblesville show a general downstream increase in streamflow per square mile of drainage area for both streams. Stream discharges were greater than 0.01 cubic feet per second per square mile for approximately 80 percent of the area and 0–0.009 cfs per sq mi for about 20 percent of the area.

C. R. Collier and J. H. Klingler found that the dissolved-solids content of water in the Mississinewa and White Rivers and their main tributaries ranged from 240 to 1,900 parts per million during the base-flow period. Water from the Mississinewa River and its tributaries contained from 337 to 1,900 ppm dissolved solids, and its hardness ranged from 300 to 700 ppm. Dissolved-solids content of water in the White River system ranged from 240 to 732 ppm, and hardness from 200 to 438 ppm. In both stream systems dissolved-oxygen and detergent parameters used to measure stream pollution were generally within permissible limits set by health authorities.

Aquifers in glacial outwash deposits

J. S. Rosenshein and J. D. Hunn (2–64) differentiated four lithologic units of glacial deposits in Porter, La Porte, and St. Louis Counties, one unit of which is the principal source of ground water in northwestern Indiana. Regional transmissibility of this aquifer ranges from about 45,000 gallons per day per foot in Porter County to about 65,000 gpd per foot in La Porte County. The potential supply available from this source is much greater than the quantity now being withdrawn.

In Vigo and Clay Counties, west-central Indiana, L. W. Cable and F. S. Watkins found the most important source of potential ground-water supply to be the glacial sand and gravel deposits in the Wabash and Eel River valleys.

IOWA

Ground water in Linn and Cerro Gordo Counties

Limestone of Silurian age is one of the most important sources of ground water in Linn County. It supplies large quantities in Cedar Rapids, one of the industrial centers of eastern Iowa. R. E. Hansen reported that extensive pumpage from this aquifer has lowered the piezometric surface more than 50 feet since the 1920's; however, the aquifer can continue to supply increasing quantities of water. Alluvial deposits filling buried bedrock valleys are also important but little-developed sources of large quantities of ground water. More than 10 million gallons per day is pumped from alluvial deposits in the city of Cedar Rapids.

The Jordan Sandstone, the principal bedrock aquifer in Iowa, is extensively developed in the Mason City area, Cerro Gordo County. Large municipal and industrial withdrawals from the aquifer have caused a water-level decline of 140 feet in the Mason City area in the last 50 years.

Ground water in Mississippian limestone

Studies by P. J. Horick and W. L. Steinhilber show that rural domestic and small municipal ground-water supplies can be obtained from limestone of Mississippian age in most of Iowa. The quality of water from this source is suitable for most purposes in much of the State; however, in south-central Iowa the quality deteriorates because of gypsum and anhydrite deposits in the source rock. Sodium and fluoride contents of the water are high in a few localities.

Drift-filled bedrock valleys as ground-water sources

Test drilling and associated studies by J. W. Cagle indicate that buried bedrock valleys filled with glacial drift are favorable areas for moderate ground-water development in south-central Iowa. Test drilling in Decatur, Clarke, Wayne, and Lucas Counties indicates as much as 425 feet of drift overlying these bedrock valleys. In much of the area the underlying bedrock yields moderate quantities of ground water, but locally the water is highly mineralized and generally inadequate to meet present-day needs.

Water resources of central Iowa

Water is available in sufficient quantity to supply the needs of a 10-county area in central Iowa and, according to F. R. Twenter and R. W. Coble, will be adequate also for most future industrial requirements.

The principal sources of water are streams, shallow alluvial aquifers, and deeper bedrock aquifers. The average flow in the major streams is more than 2.8 billion gallons per day. Shallow alluvial aquifers contain a minimum of 500 billion gallons of water in storage. Because these deposits are readily recharged they yield large quantities of water and are the principal source of ground water in central Iowa. Bedrock aquifers also contain large quantities of water, probably more than 35,000 billion gallons, and are important sources for many community supplies.

The quality of water in streams and alluvial aquifers is generally good, and the water can be used for most purposes. Water in the bedrock aquifers, however, varies in composition according to aquifer and depth. In the south and southeastern parts of the area where the ground water deteriorates in quality with depth, alternate supplies are available from shallow aquifers along streams or from the streams themselves.

MISSOURI

Mine water used by industries in southwestern Missouri

A large volume of water is in storage in abandoned zinc-lead mines in the Joplin area, according to E. J. Harvey. Early in 1964 about 3 million gallons per day was pumped from 7 mines in the area. Since these mines represent only a small part of the total mined area, a much larger quantity of water is available for future development. Pumping for industrial use, exclusive of mining and milling operations, began in the early 1940's but increased considerably in 1958. The chemical quality of the mine water varies areally and with time. Iron content of water from one mine ranged from 0.21 to 12 parts per million over a period of 5 years, and the pH ranged from 7.3 to 5.9.

Low-flow characteristics of Missouri streams

According to studies by John Skelton of low-flow characteristics of Missouri streams, poorly sustained base flows are prevalent in the Till Plains (north of the Missouri River) and the Cherokee Plains (extreme west-central part of the State). Well-sustained base flows were noted in the spring-fed streams of the Ozark Plateau section. Preliminary analysis of data indicates that streams have been observed dry at least once at 40 percent of the continuous-record stations, 90 percent of which are located in the Till Plains and Cherokee Plains regions. The records also show that 12 percent of all continuous-record stations have a median annual minimum 7-day flow of zero, and 87 percent of these are in the plains regions.

KENTUCKY

Water supply at Mammoth Cave National Park

Studies of additional water supply for Mammoth Cave National Park by R. V. Cushman, R. A. Krieger, and J. A. McCabe indicate that ample supplies of water of suitable quality can be obtained from streams in the area to meet any anticipated requirement.

TENNESSEE

Ground water in Highland Rim area

Field investigations by R. H. Bingham and G. K. Moore (2–63) in Montgomery County show that many wells in the northeastern part of the county yield water containing as much as 1,000 parts per million of sulfate. The source of this constituent is believed to be gypsum along partings and bedding planes in the St. Louis and Warsaw Limestones.

Preliminary study by J. H. Criner in the valley of Trace Creek near Waverly indicates a large amount of ground-water underflow through alluvial deposits filling the bedrock valley. Moderate supplies of ground water are believed to be available in this area, one of the most promising in middle Tennessee for industrial development.

New well field in "500-foot" sand in Memphis

D. J. Nyman, in a study of the new Lichterman well-field site, found evidence that clays capping the "500-foot" sand aquifer have been breached by Nonconnah Creek 1 mile north of the well field. When the well field begins operation early in 1965, pumping an anticipated 8 million gallons per day, recharge to the aquifer will be induced from Nonconnah Creek and the chemical quality of the water being pumped may undergo gradual change.

ALABAMA

New source of ground water in Winston County

A study of the subsurface geology of Winston County by W. J. Powell revealed extensive solution development near the contact of the Bangor Limestone and the Hartselle Sandstone at a depth of about 1,100 feet. Water in this solution system, based on interpretation of electrical logs and drilling reports, is of more satisfactory quality and quantity for municipal and industrial use than water in the overlying Pottsville Formation. This interpretation has been verified at Lynn, where water from the solution system was tapped for the first time as a source of municipal supply for the town.

Decline of artesian head in Pickens County

K. D. Wahl has observed that numerous wells in Pickens County that previously flowed have ceased flowing or decreased in rate of flow owing to a decline of artesian head. This decline has been caused by the discharge of about 2 million gallons per day, of which 1.8 mgd is not for beneficial use. The total municipal and industrial use of ground water in Pickens County is about 1.4 mgd, or less than the amount currently flowing to waste.

MISSISSIPPI

Quality of water related to aquifer permeability

In northeastern Mississippi, B. E. Wasson has found that the normal increase, with depth, of mineral constituents in ground water is reversed locally in aquifers of Cretaceous age. Mineral content usually increases downdip in aquifers in Mississippi; however, Cretaceous aquifers in northeastern Mississippi are more permeable with depth, and the deeper water in them sometimes contains less dissolved mineral salts. Tertiary aquifers have a more patternless range of permeability and contain water that generally is more mineralized in each successively deeper aquifer. The occurrence of very permeable aquifers containing good quality water at great depth is a large factor in the potential water-supply development in northern Mississippi.

Ground-water supply in Alcorn County

Pumping tests by Roy Newcome and J. A. Callahan (1-64) show wide variations in transmissibility of an aquifer in fractured chert of Paleozoic age at Corinth. In the northern part of the city, values of transmissibility are double those in the southern part, and four times those in the industrial park less than a mile south of the city. Test drilling to locate additional supply wells in the chert aquifer for municipal and industrial needs therefore is likely to be more successful in the northern area. Potentially the Paleozoic chert offers possibilities for additional withdrawal of moderately large water supplies of excellent quality. The water is superior in quality to that from the shallower Coffee Sand, which contains excessive iron but which is an important reserve supply.

Aquifers overlying Tatum salt dome, Lamar County

Studies by J. W. Lang, E. J. Harvey, R. V. Chafin, and R. E. Taylor have revealed 3 significant aquifers in the 900-foot section of Miocene clay and sand overlying the caprock of the Tatum salt dome and 1 aquifer in the limestone part of the caprock. Exploratory drilling and testing have shown that the mile-wide flat-topped rock-salt stock, which has penetrated Tertiary and older formations, is covered by a caprock 500 to 600 feet thick. In descending order the caprock consists of limestone, thin beds of gypsum, and anhydrite. The limestone is very cavernous and fractured and contains comparatively fresh water. Studies of water quality and water-level data indicate that ground water moves from an artesian aquifer in the Vicksburg Group on the flank of the dome into the limestone aquifer in the caprock and slowly percolates upward into the overlying Miocene strata. (See also "Investigations Related to Nuclear Energy, VELA UNIFORM Program.")

LOUISIANA

Potential salt-water encroachment in Geismar-Gonzales area

R. A. Long reported that large quantities of fresh water are available in most of the Geismar-Gonzales area of Ascension Parish from depths as great as 600 feet. The area is the approximate southern boundary of flushing of connate water from most of the aquifers that lie below a depth of about 300 feet. Structural and lithologic features of the aquifers complicate the fresh-water–salt-water relations. Pumping can induce encroachment of brackish or salty water from the lower parts of some of the fresh-water aquifers, laterally within aquifers, and from underlying salt-water aquifers having a higher artesian head. No significant water-level decline has been caused by pumping, and water levels remain from a few feet above to about 20 feet below the land surface. The most significant changes of ground-water levels are caused by changes in stage of the Mississippi River.

Ground water pumpage in Greater New Orleans area

Ground-water withdrawal from the "700-foot" sand in the New Orleans area has increased from about 5 million gallons per day in 1890 to about 51 mgd in 1962. J. R. Rollo reported that although the transition zone between fresh and salty water in the aquifer passes through this area, increased pumping does not appear to have caused significant advance of the salt-water–fresh-water interface. Most of the pumping is from wells located along the interface, and the pumping is believed to have formed a protective barrier that prevents the northward migration of the salt-water front. Water pumped from many of these wells is slightly to moderately saline; however, its salinity does not greatly restrict its use for air conditioning and cooling in industrial processes.

Fresh ground water under Lake Pontchartrain

G. T. Cardwell, M. J. Forbes, and M. W. Gaydos report that preliminary analysis of electrical logs of oil and gas wells and test holes in and around brackish Lake Pontchartrain indicates that fresh ground water underlies the entire lake. Depths to the base of fresh water range from 600 to 700 feet below sea level at the south shore to 3,000 feet below sea level at the north shore. Water wells about the lake margins suggest that the water is soft and is confined under artesian heads as much as 120 feet above sea level.

INTERSTATE INVESTIGATIONS

Sparta Sand environmental studies

Sand-percentage maps of the Sparta Sand, prepared by J. N. Payne (1–64), indicate a change in environment from predominantly deltaic in Arkansas, Louisiana, and Mississippi to predominantly nearshore in Texas. A comparison of sand percentage, maximum sand-unit thickness, and total thickness of fresh-water-bearing sand with available pumping-test data shows good correlation between sedimentation, lithology, and transmissibility. Initial studies of water quality in the Sparta Sand suggest a relation between maximum sand-unit thickness and water quality.

Water resources of the Mississippi embayment region

M. S. Hines, A. J. Calandro, and P. R. Speer found that streams in the embayment section of southern Arkansas that receive their base flow from sands of the Claiborne Group have better sustained low flows than those that receive their base flow from other geologic units. Streams that lie in the Quaternary alluvium and terrace deposits west of Crowley Ridge near lat 35° N. have relatively low base flows, but farther south at about lat 32°30′ N. in Louisiana where larger streams such as Boeuf River, Tensas River, and Bayou Macon are incised into aquifers in the basal part of the alluvium, the base-flow yields are higher. In the embayment as a whole, the low-flow indices for streams east of the Mississippi River in Alabama, Mississippi, and Tennessee are much higher than those for streams west of the Mississippi River and north of Tennessee.

E. H. Boswell (2–63), G. K. Moore, and L. M. MacCary found that aquifers of Cretaceous age are used as sources of water supply in an area of about 30,000 square miles and are potential sources in an additional 15,000 square miles. The more extensive aquifers of Cretaceous age, the Ripley, Eutaw, and Gordo Formations, are in the eastern and northern parts of the embankment. Generally these aquifers are not extensively developed, the total withdrawal being about 90 million gallons per day.

R. L. Hosman reported that data from a deep test hole drilled near Pine Bluff, Ark., indicate a new potential ground-water supply for a large area in the south-central part of the State (chapter D). The Carrizo Sand, virtually an undeveloped aquifer in Arkansas, was found to contain fresh water at a depth of more than 2,000 feet. The Carrizo Sand had not been tested previously, primarily because it is overlain by shallower highly productive aquifers. It represents an important ground-water reserve in the event that existing supplies are depleted and become inadequate to meet increased water demands.

Ground water in Wabash River basin

A reconnaissance investigation by F. A. Watkins (3–64) and P. R. Jordan indicates that large supplies of ground water are available for development in the Wabash River basin. The magnitude of the supply is indicated by the overflow of ground water into the rivers, which exceeds 3,400 cubic feet per second during base-flow periods.

Nearly all this overflow is from the shallowest of the 3 principal aquifers, the glacial outwash, which yields more than 500 gallons per minute to wells less than 200 feet deep near the major streams. Limestone formations in the northeastern part of the basin yield 200 to 500 gpm to wells that penetrate about 300 feet of the aquifer, but deeper wells in the limestone produce salty water. A buried river valley extending west from Tippecanoe County, Ind., is filled with glacial outwash deposits that yield 100 to 500 gpm to wells 100 to 400 feet deep.

Hardness of nearly all the water from these 3 sources is greater than 250 parts per million, but the water is suitable for many uses after little or no treatment.

ROCKY MOUNTAIN AREA

The wide diversity of hydrologic, climatic, and physiographic conditions, as well as expanding cultural developments, gives rise to varied and complex water problems in the Rocky Mountain area. Included in this discussion are 12 of the 17 Western States; the States of California, Oregon, Washington, Idaho, and Nevada are excluded. Most critical are supply problems in the arid regions of the Southwest, where "population explosions" in urban centers are resulting in rapidly increasing demands on available supplies.

There is an expanding interest in the development of ground water and the possibilities for the management of underground reservoirs to supplement surface-water supplies. Overdevelopment resulting in the lowering of water tables is cause for concern in many areas and has increased the demand for quantitative evaluation of ground-water resources. Several years of deficient precipitation have also accelerated interest in the evaluation of total water supplies and in the need for conservation.

Problems of quality of both surface and ground waters are of considerable concern in many areas. The use and reuse of available supplies, whether for irrigation, domestic, or industrial uses, inevitably cause some deterioration in quality. Moreover, many prospective supplies may be unsuitable for some uses, because of natural pollutants.

Investigations of the U.S. Geological Survey are directed toward the collection of water facts and the conduct of studies that will aid in the resolution of these water problems. Some of the significant results of these investigations in the Rocky Mountain area are reported in the following section.

MONTANA

Thick valley fill in Missoula structural valley

As part of a ground-water investigation of the Missoula structural valley by R. G. McMurtrey, R. L. Konizeski, and Alex Brietkrietz, a gravity survey aided in determining configuration of the bedrock floor of the valley and indicated a maximum thickness of fill of about 2,750 feet.

Large development of artesian water in eastern Montana

An investigation by O. J. Taylor of the Fox Hills-Basal Hell Creek artesian aquifer on the western flank of the Cedar Creek anticline in eastern Montana indicates that very little recharge occurs in the narrow outcrop, because of low precipitation, low aquifer transmissibility, and small outcrop areas. About 4 billion gallons of ground water will be withdrawn from industrial wells in the artesian aquifer in the next 21 years, which can be expected to affect artesian head in wells west of the anticline and the water table in the outcrop area.

Ground water in Missouri River valley

An investigation of the Missouri River valley of northeastern Montana by W. B. Hopkins indicates that a considerable amount of water is available for irrigation, municipal, and industrial use but that water quality is a problem locally. Six lines of test holes were drilled across the bottom land to determine the thickness and extent of permeable gravel in the valley fill. Permeable gravel averages about 30 feet in thickness at the base of the valley fill, and is widespread but not uniformly distributed. Pumping tests indicate well yields as great as 1,500 gallons per minute where the gravel is more than 20 feet thick. Water from wells near enough to the Missouri River to induce infiltration of water from the river generally is of better quality.

High artesian head in part of Judith Basin

Studies of the western part of the Judith Basin, Mont., by E. A. Zimmerman reveal that the artesian head in some wells is more than 160 feet above land surface. These high artesian heads were measured in wells that penetrate sandstone beds in the Kootenai Formation of Early Cretaceous age—one of the most used aquifers in the western part of the Judith Basin. The water from this aquifer generally is of good quality, although dissolved gases in water from wells of high head make it corrosive to casing and plumbing.

NORTH DAKOTA

Drainage reversal in Burleigh County

According to P. G. Randich (1–64), the preglacial eastward drainage channels in Burleigh County also were ice-front valleys of southwestward-moving glaciers. The largest concentrations of buried and surficial gravel, which yield water freely to wells, are along the northern edges of these channels. Tributaries generally contain only fine-grained sediments, are narrow, and have steeper gradients than the main channels. The present drainage is westward.

Extensive sand aquifer in Richland County

Q. F. Paulson and C. H. Baker, Jr., report that test drilling in Richland County indicates an extensive and productive aquifer in the sand deposits of the Sheyenne delta (chapter D). More than 100 feet of medium- to coarse-grained sand was penetrated in some places. The ground water generally has a low dissolved-solids content but is hard, and locally it contains considerable iron. Recharge potential is good, as the sand is exposed over a wide area. The water table generally is less than 10 feet below the land surface. The Sheyenne River picks up a considerable amount of ground water along its course through the delta.

Buried-valley aquifer in Barnes and Stutsman Counties

According to T. E. Kelly, the Spiritwood buried-valley deposits underlie approximately 350 square miles of western Barnes and eastern Stutsman Counties. Also, logs of test holes drilled north of Sutton, in Griggs County, 13 miles north of the Barnes County line, suggest a northward extension of the buried-valley deposits. Two aquifer tests in November 1963 on wells 12 miles apart in the buried-valley deposits indicate a coefficient of transmissibility of approximately 30,000 gallons per day per foot and a coefficient of storage of 0.008. This extensive aquifer, which contains water of fair to good quality, is virtually undeveloped at present.

Buried outwash aquifer in Foster County

Henry Trapp, Jr., reported that test drilling in northwestern Foster County indicates that the Carrington aquifer, a buried outwash sheet, adjoins other outwash bodies at different levels. Wells in the aquifer supply the town of Carrington and the Carrington irrigation branch station. Properly constructed wells yield as much as 1,700 gallons per minute. Outwash in the area is found from the surface to depths of about 100 feet, but the principal aquifer, the Carrington, is about 50 feet below the surface.

Buried valley of Yellowstone River in Divide County

Studies in Divide County by C. A. Armstrong indicate that wells in the larger outwash deposits yield as much as a few hundred gallons per minute, but that wells in small stringers of sand near prairie potholes generally yield only enough water for domestic use. Test drilling indicates that the buried preglacial valley of the ancestral Yellowstone River is considerably lower than that of the ancestral Missouri River.

WYOMING

Ground water in Powder River Basin

Completion of hydrologic studies of the western part of the Powder River Basin by M. E. Lowry, H. A. Whitcomb, T. R. Cummings, and R. A. McCullough reveals that supplies of ground water adequate for stock and domestic use generally can be developed from relatively shallow wells in the Wasatch and Fort Union Formations. Flowing wells are common because of artesian head and, in some places, because of gas pressure in the aquifers. The chemical quality of the water differs greatly throughout the area, ranging from good to poor. Supplies adequate for moderate- to large-scale irrigation development probably can be obtained from the Tensleep Sandstone and from cavernous zones in the Madison Limestone in a narrow band along the western margin of the basin in central Johnson and northern Sheridan Counties. However, the strata dip steeply basinward, and drilling to them would not be feasible beyond a short distance from the outcrop. The chemical quality of the water near the outcrop is good enough that the water should be suitable for irrigation. At present, irrigation water is obtained largely from streams.

Productive aquifer in Grand Teton National Park

A previously untapped alluvial aquifer was found east of Jackson Lake in Grand Teton National Park by J. McGreevy and E. D. Gordon (1–64). More than 100 feet of saturated sand and gravel was located in the Pilgrim Creek valley north of Jackson Lake Lodge. Yields of several hundred gallons per minute are available, and the water is of good quality for drinking and most other uses (100 parts per million of dissolved solids). A public-supply well drilled in 1964 to provide additional water for developments at Colter Bay and at Jackson Lake Lodge yields 270 gpm. Much larger yields are available from this aquifer to meet increased future requirements.

SOUTH DAKOTA

Summary of water resources

In a description of the water resources of South Dakota, J. E. Powell, J. E. Wagar, and L. R. Petri [29] report that municipal water systems delivered 54.5 million gallons per day in 1960, an average of 132 gallons per capita per day. About 96 percent of the supply came from ground water. Ground-water supplies for irrigation in 1960 totaled 77,000 acre-feet, 45 percent of all water used for irrigation.

Deep ground water in western South Dakota

According to C. F. Dyer and M. J. Ellis, several oil-test holes drilled recently at widely separated localities have supplied valuable information on the artesian-water resources in western South Dakota. At least two of the holes have been completed as water wells. One oil-test hole in northeastern Stanley County was drilled to a total depth of 3,992 feet, plugged back to 2,538 feet,

[29] J. E. Powell, J. E. Wagar, and L. R. Petri, 1964, Water resources, *in* Mineral and water resources of South Dakota: U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs Rept. [In press]

and gun-perforated from 2,412 to 2,430 feet. The well flows about 50 gallons per minute of warm highly mineralized water. Shut-in pressure at the land surface is 151 pounds per square inch. The water-bearing unit is a bed of gray sandstone 18 feet thick that is probably a basal Cretaceous sandstone deposited on an erosion surface of Jurassic age. No other wells are known to obtain water from this unit.

Estimate of withdrawal of water from Dakota Sandstone

C. F. Dyer and A. J. Goehring report that an estimated 62 million gallons per day of water is withdrawn from the Dakota Sandstone in 21 counties of southeastern South Dakota. This estimate is much higher than earlier ones. Rural users withdraw nearly 61 mgd; about 24 mgd by wells flowing more than 20 gallons per minute, about 33 mgd by wells flowing less than 20 gpm, and about 3.6 mgd by pumped wells. Municipalities withdraw 1.6 mgd by pumped or flowing wells. At least two-thirds of the 24 mgd withdrawn by wells flowing more than 20 gpm is unused. (See also "Ground Water.")

Ground water in glacial drift in Sanborn County

Studies by L. W. Howells indicate that more than 2.2 million acre-feet of water is in transient storage in glacial-drift aquifers that underlie more than 400 square miles of Sanborn County. Although the water is somewhat saline, it can be used for irrigation if salt-tolerant crops are grown and salinity-control practices are followed. Although relatively undeveloped, the Greenhorn Limestone is an aquifer throughout much of the county. Water from the Greenhorn normally is soft, saline, of sodium sulfate type, and contains as much as 4.5 parts per million of boron. Geochemical and drilling data indicate that the Greenhorn receives recharge of very hard calcium sulfate water from the Dakota Sandstone near highs in the Precambrian surface in southeastern Sanborn County.

Ground water in Skunk Creek-Lake Madison area

According to M. J. Ellis and D. G. Adolphson, the glacial outwash in the Skunk Creek-Lake Madison drainage basin is not fully developed as a source of ground water, and can yield large additional supplies for irrigation and industrial use. In 1962, the outwash held an estimated 167,000 acre-feet of ground water in transient storage. Water from the outwash is very hard, but otherwise is of good quality; most of it is suitable for irrigation and industrial use. Of the estimated 768,000 acre-feet of water that enters the drainage basin each year as precipitation, 44,500 acre-feet leaves by surface runoff, about 700 acre-feet leaves by ground-water outflow, and the rest, 722,800 acre-feet, is lost by evapotranspiration.

Large outwash aquifer in Big Sioux River basin

M. J. Ellis and D. G. Adolphson report that glacial-outwash deposits occupy an estimated 55,700 acres in the Big Sioux River drainage basin in South Dakota, between Brookings and Sioux Falls, and have great potential for future ground-water development. Test drilling indicates that the outwash sand and gravel deposits are as much as 50 feet thick and average about 25 feet in thickness.

Springs on Pine Ridge Indian Reservation

M. J. Ellis reports that springs at contacts along the northern and southern boundaries of the Pine Ridge Indian Reservation are an important source of good quality water, particularly along the northern edge of the reservation, where the aquifers used elsewhere are thin or absent. The springs along the northern boundary are at contacts between (1) terrace deposits and the Pierre Shale or White River Group, (2) Arikaree Formation and White River Group, and (3) eolian sand deposits and the White River Group. Along the southern boundary of the reservation, the springs occur at the contact between eolian sand deposits and the Ogallala Formation or the Arikaree Formation.

NEBRASKA

Saline water migrates from underlying Dakota Sandstone

Philip A. Emery reports localized bodies of saline water in some Pleistocene aquifers in the southeastern corner of Saline County, apparently owing to movement of water with high chloride content from the Dakota Sandstone into the overlying Pleistocene deposits.

Huge ground-water reservoir beneath Adams County

Although more than 650 irrigation wells each yield an average of about 1,000 gallons per minute to irrigate more than 60,000 acres in Adams County, C. F. Keech reports that the ground-water supply will be adequate for many years to come. During the last 10 years, water levels in wells in the vicinity of Hastings have declined an average of more than half a foot per year, but in the later years, water levels generally have declined at a smaller rate, and some have risen. Thick deposits of saturated sand and gravel of Pleistocene age underlie all of Adams County and contain an estimated 11.5 million acre-feet of water. Precipitation is the principal source of recharge to the reservoir, but some seepage from the tri-county irrigation district, which is irrigated with water diverted from the Platte River, enters by underflow from the west.

UTAH

Summary of water resources

In a report on statewide mineral and water resources, M. T. Wilson, R. H. Langford, and Ted Arnow (U.S. Geological Survey, 9–64) show that Utah's water supply is substantial, but is small in relation to the large area and potential water demand of the State. Annual runoff averages 7,600 million gallons per day. Fresh-water use in 1960 was about 3,900 mgd, mostly for irrigation, which accounted for 3,350 mgd. Hydroelectric power, a nonconsumptive use, required about 1,800 mgd.

Saline water from faults contaminates shallow aquifers in Tooele Valley

J. S. Gates reports that wells and springs near three inferred faults in Tooele Valley yield thermal water of high chloride content which apparently rises along the faults and contaminates shallow ground water. Four springs and 31 of 34 wells near the inferred faults yield water that contains more than 300 parts per million chloride and is from 2° to 32° F above normal ground-water temperature. Water from 2 of the springs and 5 of the wells contains more than 1,000 ppm chloride and averages 17° F above normal.

Little change in quality of wells and springs

Utah now has a network of 295 wells and springs in areas of considerable population and water development, from which analyses of water are collected periodically to determine changes in quality of water. C. A. Horr reports that analyses of water samples collected during 1957–62 have shown very little change in chemical character, except for ground water in southern Pavant Valley (reported in 1963 by R. W. Mower in U.S. Geological Survey, 18–63, p. 439) and from a few wells in other areas. Seasonal changes in content of dissolved solids are less than 10 percent from most wells. Total content of dissolved solids in most wells is less than 1,000 parts per million, but ranges from about 100 to 3,000 ppm.

Additional ground-water development possible in upper Sevier River basin

According to C. H. Carpenter, G. B. Robinson, Jr., and L. J. Bjorklund, large quantities of ground water are stored in valley fill of the upper Sevier River drainage basin above Kingston. Sand and gravel beds in the upper 200 feet alone (more than 800 feet thick in some places) contain about 1 million acre-feet of water. The annual discharge of ground water from the alluvium includes about 27,000 acre-feet from springs, 43,000 acre-feet by evapotranspiration, 3,000 acre-feet from wells, and 3,000 acre-feet from drains. This represents about 8 percent of the water in storage in the upper 200 feet of alluvium. It is estimated that about 15,000 acre-feet of additional ground water might be developed from the alluvium in the various valleys by lowering water levels and thus salvaging part of the water discharged by evapotranspiration.

Sinkholes in alluvium give clue to hidden solution openings in limestone

According to L. J. Bjorklund and G. B. Robinson, Jr., sinkholes in the north half of Scipio Valley, a closed basin, and in the hills to the north have developed along fault lines in limestone beds of the North Horn and (or) Flagstaff Formations of Late Cretaceous and Tertiary age. Solution channels drain Scipio Valley and control ground-water levels in the northern half of the valley; water from the valley moves through the channels and discharges from Moulten and Blue Springs. An apparent lack of large fluctuation in spring discharge indicates that a large amount of water is in storage.

Great Salt Lake approaching stabilized low level

Great Salt Lake reached its lowest level in recorded history on November 1, 1963, when its elevation receded to 4,191.3 feet above mean sea level. This is a decline of 20.3 feet from the all-time high recorded in 1873. The decline in lake level has also reduced the water area from 1,500,000 acres to about 600,000 acres, with a proportionate reduction in evaporation losses. It is believed that at present levels, inflow and evaporation are about equal and that the lake level will not recede materially in the near future.

Reduced water supply in northern Utah Valley,

R. M. Cordova reports that the amount of surface inflow to northern Utah Valley generally has declined since 1946, even though the amount of imported water has increased. It is assumed also that the amount of recharge to ground water also has declined. However, the decreased recharge and increased pumping have not caused water-development problems in the area.

COLORADO

Summary of water resources

In a statewide summary on water resources, John W. Odell, Donald L. Coffin, and Russell H. Langford find that a substantial supply of water is available in most of Colorado, particularly in the mountain areas adjacent to the major streams, and in areas underlain by extensive aquifers. Supplies generally are of good quality in the mountain areas but deteriorate progressively downstream owing to increased mineralization caused by return flow from irrigation and to contamination from industrial and municipal wastes. An average of about 16 million acre-feet runs off in the major streams. In 1960 about 10.8 million acre-feet was used, mostly for irrigation. Interstate compacts and Supreme Court decrees limit consumptive use to somewhat less than half the average yield of water. Future development of water resources will depend increasingly on additional storage, reuse of available supplies, and management practices that reduce consumptive use by nonbeneficial plants and increase efficient use of surface- and ground-water supplies.

Ground water in Pueblo and Fremont Counties

A study by H. E. McGovern, E. D. Jenkins, and Robert Brennan describes the quantity and quality of ground water from the Pleistocene and Recent deposits in parts of Pueblo and Fremont Counties. During the study, average pumpage in the area was 37,000 acre-feet per year, and average annual diversion from the Arkansas River and Fountain Creek was 412,000 acre-feet. About 75,000 acre-feet, or 26 percent, of the water diverted for irrigation below Pueblo was available for reuse through return flow and ground-water recharge.

Recharge from floods along Middle Big Sandy Creek

Flow measurements by D. L. Coffin in the Big Sandy Creek valley of east-central Colorado indicate that percolation of flood flows is a major source of recharge. This is indicated by rising water levels in wells during floods and by the downstream exponential decrease in channel width. Measurements indicate that about 3 feet of water is recharged during a bankfull flood. The data also indicate that the vertical permeability of the valley fill is less than $\frac{1}{10}$ of the horizontal permeability.

Irrigation wells increasing in Colorado high plains

The number of irrigation wells tapping the Ogallala Formation of the Colorado high plains is increasing at a rate of about 100 per year. In 1963, at least 525 irrigation wells were being used, each of which pumped more than 300 gallons per minute, according to A. J. Boettcher. Comparison of the water requirements of the crops and the average per acre use indicates that the amount of water pumped in 1962 (72,500 acre-feet) was about the same as the potential consumptive use computed by the Blaney-Criddle method.

Water management in Arkansas River valley

A pilot study by E. A. Moulder and others (2–63) of a 25-mile reach of the Arkansas Valley has shown that the ground-water reservoir can provide additional supplemental water for irrigation and that substantial amounts of water now consumed wastefully by phreatophytes can be salvaged. Analysis of ground-water and surface-water records for 1940–60 indicated that the consumptive use of water in the study reach increased by about 20,000 acre-feet, although the irrigated acreage remained practically the same. The major factor causing increased consumptive use is the increased use of ground water to supplement the surface-water supply.

KANSAS

Ground-water levels in Grant and Stanton Counties

J. D. Winslow, C. E. Nuzman, and S. W. Fader (1–64) report that ground-water levels in Grant and Stanton Counties continued to decline at an alarming rate during 1963. Water-level-change maps show the decline in water levels from the 1940 base to be more than 90 feet in the area of greatest decline, approximately 8 miles southeast of Ulysses. The decline has been more than 20 feet over an area of approximately 570 square miles.

Increased dissolved solids and chloride in South Fork Ninnescah River

A quality-of-water survey in April 1963 and monthly data from four chemical-quality stations in the South Fork Ninnescah River basin indicated to A. M. Diaz the location of an increase in total dissolved-solids and chloride content. The major increase in chloride concentration occurs between Cairo and Cunningham and is caused principally by inflow of natural brines from underlying formations of Permian age and from localized pollution of shallow ground water in or near oil fields. Total dissolved-solids and chloride concentrations ranged from 217 to 1,150 parts per million and from 12 to 534 ppm, respectively, in the main stem. The water in most of the tributary streams is of good quality and has a relatively low dissolved-solids contents.

ARIZONA

Ground water in Big Sandy Valley, Mohave County

An investigation of the Big Sandy Valley, Mohave County, by William Kam, indicated that Recent stream deposits are capable of yielding large quantities of water to wells. In the 21-year period 1940–60, water levels in observations wells showed little net change, indicating that draft has not exceeded the perennial recharge to the aquifer. Surface and subsurface outflow, excluding floodflow, is about 2,000 to 3,000 acre-feet per year.

Water shortage at Williams due to leaky reservoirs

The city of Williams has a serious water-supply shortage despite average annual precipitation exceeding 20 inches. Studies by B. W. Thomsen indicate that the 7 public-supply reservoirs impound sufficient surface runoff in 1 year to meet the demand for several years, but that seepage from the reservoirs results in rapid escape of the stored water. The rocks underlying the reservoirs are highly permeable, and the seepage probably drains to the regional water table, which is more than 2,300 feet below land surface at Williams.

Aquifer serves as regulating reservoir for Verde River

An annual water yield of about 5,000 acre-feet is obtained from 165 square miles of a dominantly granitic mountainous area in Maricopa County that receives an average annual precipitation of 18 inches, according to B. W. Thomsen and H. H. Schumann. Only 5 percent of this water reaches the Verde River as surface flow over a 9-mile reach of alluvial channel below the mountain front. Only when flow from the hard-rock area exceeds 200 cubic feet per second does any surface flow reach the Verde River. The 95-percent "loss" is temporarily stored in the ground-water reservoir formed by permeable materials in the lower 9-mile reach of the stream. Some of this water is lost by evapotranspiration and some is slowly released to the Verde River as underflow out of Sycamore Canyon.

Ground-water movement in Mogollon Rim area

One of the controls of water movement in the Mogollon Rim area of northern Arizona is the relation of topography to structure. Compilation of structural data by T. L. Finnell indicates that a 5-mile-wide belt of northwestward-trending en echelon high-angle faults and small domes extends along the steep south-facing Mogollon Rim for about 20 miles west of Show Low, in Navajo County. This belt forms a structural barrier to the migration of ground water which normally would move northward down the regional dip to the Little Colorado River basin. Instead, water percolating along permeable beds is probably deflected southward to issue as springs that feed the Salt River.

Ground-water flow net aids hydrologic studies in central Arizona

According to W. F. Hardt, a ground-water flow net including the central part of Arizona from Red Rock to Phoenix shows that (1) regional ground-water movement corresponds to major drainages and is locally deflected by the mountains, (2) the ancestral Gila River probably was formerly north of its present course in the reach from Florence to the Salt River, and (3) the average coefficient of transmissibility of the alluvial aquifer is about 100,000 gallons per day.

Streams could supply one-third of water needed by Fort Huachuca

S. G. Brown, L. R. Kister, and B. W. Thomsen report that about one-third of the average water demand of Fort Huachuca, Cochise County, can be met from the flows of creeks and springs in the Huachuca Mountains. Use of this water would relieve some of the demand on the present well field. The water from the creeks and springs has a very low sediment and total dissolved-solids content, and would be suitable for use in the present water system with minimum treatment. In places the water from creeks and springs is supersaturated with calcium carbonate, which must be removed before recharge through wells or infiltration pits could be practiced with any water in excess of the demands of the fort.

NEW MEXICO

New well for Carlsbad Caverns supply

According to W. A. Mourant and J. S. Havens (1–64), one of several test holes drilled in the Rattlesnake Springs area, Eddy County, could be developed as a well that will readily yield the 225 gallons per minute required for the Carlsbad Caverns water supply, and probably would yield more than 1,000 gpm. The quality of the water in Rattlesnake Springs improves when the pool is lowered by pumping of irrigation wells to the southwest. The better quality water entering the pool probably moves from the west or northwest through solution channels in conglomerate.

Deep test well yields rare gases

A test well 1,675 feet deep drilled at Mesita pueblo, Valencia County, in search of a water supply yielded appreciable amounts of carbon dioxide, nitrogen, helium, and argon. According to G. A. Dinwiddie, the well penetrated 1,620 feet of the Triassic Chinle Formation and 55 feet of the Permian San Andres Limestone. Water from a zone in the San Andres between 1,649 and 1,650 feet flowed 4 gallons per minute at the surface, had a temperature of 60°F, and a specific conductance of 23,000 micromhos at 25°C. Analysis of gas from the well indicated mainly carbon dioxide and nitrogen and some helium and argon. Water from another zone in the San Andres from 1,663 to 1,665 feet increased the flow to 15 gpm, had a temperature of 83° F, and a specific conductance of 25,000 micromhos. Another analysis of the gas yielded similar results. Although the water was unsuited for domestic use, the test is of interest because of the rare gases that issued with the water.

In adjoining Bernalillo County, H. E. Koester reports significant differences in the composition of gases yielded with ground water. Carbon dioxide is the principal gas present, composing as much as 98.4 percent of some samples from along the eastern flank of the Acoma sag. Nitrogen and helium exceed 2 percent only in deeper parts of the Acoma sag. Helium appears to be restricted to the San Andres Limestone and the

Glorieta Sandstone (both of Permian age); only trace amounts were yielded from rocks of Pennsylvanian age.

Ground-water supplies in southern San Juan Basin

A recent well-drilling program on public domain lands in the southern San Juan Basin in northwestern New Mexico indicates that small to moderate amounts of water, suitable for livestock and construction use, can be obtained from sedimentary rocks of Late Cretaceous and Tertiary age underlying the area, according to M. C. Van Lewen. Of 39 wells, 13 yielded in excess of 20 gallons per minute, 24 yielded from 4 to 20 gpm, and 2 yielded less than 3 gpm and were abandoned. Depths of the wells ranged from 125 to 960 feet, and water levels stood as much as 486 feet below the land surface. Total concentrations of dissolved solids in the water ranged from approximately 500 to 8,000 parts per million. Yields of more than 100 gpm of moderately mineralized water were obtained from sandstones in the Nacimiento Formation. All formations in the Mesa Verde Group yielded from 5 to 50 gpm of water more highly mineralized than that obtained from the Nacimiento. Yields from the Ojo Alamo Sandstone generally were small, probably because of the high degree of cementing. Small yields of water containing hydrogen sulfide were obtained from coal beds in the Fruitland Formation. A few wells tapped standstone beds in the upper part of the Kirtland Shale. Very small yields of highly mineralized water were obtained from the Pictured Cliffs Sandstone, and no water of usable quality was found in the Lewis Shale.

OKLAHOMA

Summary of water resources

In study of statewide water resources, T. B. Dover, A. R. Leonard, and L. L. Laine estimate that the annual water supply averages roughly 17 billion gallons a day, not all of which can be captured, as for example, excessive flood waters. About 1 billion gallons a day is withdrawn for use, two-thirds of it surface water, mostly in the east, and one-third ground water, mostly in the west. Future growth of water use is indicated by recent growth in a 20-year period: irrigation, from 3 to 240 million gallons per day; municipal, from 90 to 200 mgd; and industrial, from 30 to 520 mgd.

Undeveloped ground-water reserves in Woodward County

P. R. Wood and B. L. Stacy (1–63) report that the ground-water resources of Woodward County are largely undeveloped. They estimate that approximately 1.3 million acre-feet of ground water is stored in the unconsolidated alluvial deposits of the North Canadian River valley and about 3 million acre-feet in the Ogallala Formation, which covers the southwestern part of the county. Present use of water from wells for all purposes in the county is less than 10,000 acre-feet per year.

Alluvium of Arkansas River valley is a reservoir

Recent studies by Harry H. Tanaka indicate that a ground-water reservoir of considerable magnitude underlies the 100-mile segment of the Arkansas River valley between Muskogee, Okla., and Fort Smith, Ark. The total area of the alluvium is about 90,000 acres, its thickness averages 42 feet, and the thickness of saturated material averages about 27 feet. Assuming an average specific yield of 20 percent, the available water stored in these deposits totals almost half a million acre-feet. Annual recharge to the alluvium is computed to be 9 inches, or approximately 60,000 acre-feet. Total annual pumpage from the alluvium (in 1963) was estimated to be 1,700 acre-feet, or less than 3 percent of annual recharge. The water table in the alluvium declined an average of about 7 feet during 1962 and 1963, because of deficient rainfall. At Webbers Falls, near the middle of the segment, precipitation was about 27 inches less than the normal 86 inches for the 2-year period. Because they respond rapidly to recharge from precipitation, water levels are expected to recover promptly when precipitation returns to normal.

Surface-water resources of Kiamichi River basin

L. L. Laine (1–63) finds that base flow in the Kiamichi River basin is small in the Ouachita Mountain province, which comprises the larger part of the basin, but that there is considerable pickup of ground water in the Coastal Plain province, in the lower part of the basin. From samples collected during base-flow periods, T. L. Cummings concluded that the surface water of the basin is of excellent quality for most domestic, industrial, and agricultural uses. The water is soft, and the specific conductance generally is less than 100 micromhos at 25°C. Streams draining rocks of Mississippian and Pennsylvanian age in the Ouachita Mountains generally contain less chloride than those draining Cretaceous rocks of the Coastal Plain province.

Surface water in Little River basin

A study by A. O. Westfall (1–63) of streamflow records in the Little River basin in southeastern Oklahoma shows that during the period 1930–61 the surface-water yield averaged 2.4 million acre-feet per year and ranged from 1 million acre-feet in the worst drought year to almost 5 million acre-feet in wet years.

TEXAS

Electric analog duplicates operation of Houston aquifer

An electrical analog model of the aquifer underlying the Houston district was constructed under the direction of E. P. Patten, Jr., from data compiled and analyzed by L. A. Wood and R. K. Gabrysch (1–64). The model was tested and modified until it would duplicate historical water-level-decline maps for different periods of pumping. After it was verified that the model was an analog of the aquifer, water-level decline through 1970 was predicted from the amount and distribution of future pumping as estimated by city of Houston officials.

Base flow of Sabine River, Texas-Louisiana

S. P. Sauer and Jack Rawson found that in 268 miles, the base flow of the Sabine River increased from 43.4 to 470 cubic feet per second. The largest gains were in the southern half of the study area. Much of the gain was attributed to direct ground-water accretions to the main stem; measured tributary inflow was 218 cfs, only about 51 percent of the total gain. The dissolved-solids concentrations in the main-stem water ranged from 118 to 505 parts per million. In some reaches the amount of dissolved solids, particularly sodium chloride, increased significantly; but in other reaches the dissolved solids decreased much more than could be ascribed to the volume and quality of measured inflow. The wide variation of sodium chloride indicated intermittent pollution of the river by slugs of brine.

Base flow of Blanco River

H. D. Buckner and G. L. Thompson (1–64) found that the 15-mile reach of the Blanco River upstream from Wimberley, Tex., had an increase in base flow of 28.4 cubic feet per second exclusive of 14.2 cfs tributary inflow. The study was made of the 27-mile reach upstream from Wimberley and included the site proposed for the Cloptin Crossing Reservoir. The upper 12 miles of the reach lost all surface flow (1.5 cfs measured) to the exposed Hensell Sand and Cow Creek Limestone Members of the Travis Peak Formation. In the reach crossed by the Spring Branch fault (about 12 miles upstream from Wimberley), springs discharge about 14 cfs into the Blanco River. In this reach, water under hydrostatic head in the lower member of the Glen Rose Limestone or in the Cow Creek Limestone Member, or in both, evidently moves upward along the fault zone and discharges through the gravels of the streambed. The Tom Creek fault (about 7 miles upstream from Wimberley) was found to be taking 1.6 cfs streamflow, while the Wimberley fault system was discharging about 12 cfs in the 6-mile reach immediately upstream from Wimberley.

Base flow of Lampasas River

W. B. Mills and Jack Rawson (1–64) found that during periods of base flow, the lower 80 miles of the Lampasas River in the Brazos River basin is a gaining stream. In the reach studied, the flow increased from 2.27 to 16.0 cubic feet per second, a gain of 13.7 cfs. Tributary inflow was 19.2 cfs. Dissolved solids ranged from 887 parts per million near the head of the reach to 247 ppm near the mouth. The water with the higher dissolved-solids content at the head of the reach was contributed by Sulphur Creek, a spring-fed stream. Below the confluence of Sulphur Creek with the Lampasas River, ground-water accretions and tributary inflow generally diluted the river water.

Base flow of Cibolo Creek

P. H. Holland and C. T. Wellborn (4–64) found that the base flow increased from no flow to 18.6 cubic feet per second in the lower 80-mile reach of Cibolo Creek. Base flow in the upper 23 miles of the reach was sustained solely by sewage effluent (1.77 cfs, including flow from storm sewers) from the Randolph Air Force Base complex near San Antonio. About 95 percent of the base-flow gain found in the 80-mile reach originated in a 27-mile reach beginning about 23 miles downstream from Randolph Air Force Base. The inflow in this reach came from rocks of the Wilcox and Claiborne Groups; about 70 percent from the Carrizo Sand of the Claiborne Group. In the lower 30 miles of the reach, although a gain of only 0.4 cfs was found, considerable interchange of ground and surface water is indicated.

COLORADO RIVER BASIN

Effects of water use on Upper Colorado River basin

A study of the effects of natural factors and water-use developments on stream regimen in the Upper Colorado River basin recently completed by W. V. Iorns, C. H. Hembree, and G. L. Oakland indicated that with the facilities existing in 1957 for storage, withdrawal, and use of water, the average annual yield of water from the upper basin as measured at Lees Ferry, Ariz., was 12.733 million acre-feet. Average annual dissolved-solids discharge was 8.676 million tons, and the weighted-average concentration was 501 parts per million. Had the developments not been in existence the hypothetical average annual water yield at Lees Ferry would have been about 15.2 million acre-feet, the hypothetical dissolved-solids annual discharge would have been about 5.2 million tons, and the hypothetical average concentration would have been about 253 ppm. Substantially all the increase in dissolved-solids discharge is construed as an effect of irrigation on 1.4 million acres of land, which contributed an average of 2.4 tons of dissolved solids per irrigated acre per year. From one part of the area to another, this contribution ranges from 0.1 ton to 5.6 tons. Most of the water originates from the melting of snow in the mountains and high plateaus, but most of the dissolved solids comes from the lower parts of the basin where little water is contributed to the streams. The rocks exposed in the mountains generally are more resistant to the solvent action of water than the rocks which underlie the lowlands. Man's activities are mostly confined to the lowlands where rocks of Tertiary and Cretaceous age are at the surface.

PACIFIC COAST AREA

The Pacific coast area comprises the States of Alaska, Washington, Idaho, Oregon, Nevada, California, and Hawaii. Collectively, the area is characterized by a widely diversified spectrum of water-resources problems. The difficulties in overcoming these problems are compounded by the extreme contrasts in geologic and hydrologic environment, and by the ever-increasing demands of industry, public supply, and crop production. The problems are rendered more complex by the effects, sometimes deleterious, of multipurpose water demands on existing surface-water and ground-water reservoirs.

One of the most spectacular hydrologic features of the several States that constitute the Pacific coast area is the extreme range in precipitation. Places occur in each of the States where the average annual precipitation is 8 inches or less. Places also occur in each, except Idaho and Nevada, where the average rainfall exceeds 100 inches—in Washington and Alaska, over 200, and in Hawaii, over 400 inches. Unfortunately, the areal distribution of rainfall does not correspond with the regional water demands. As a result, much of the runoff in some areas is not used and probably never will be consumed within the watershed. Elsewhere, irrigation or public-supply and industrial demand so greatly exceeds the local available runoff that importation of water is necessary. Examples of such areas are southern California and central Washington.

Locally, such as in much of the Puget Sound lowland in Washington, application of prudent water-management policies can insure an equitable balance between available water and multipurpose demand for many years in the future.

The U.S. Geological Survey currently is making water-resources studies in all States in the Pacific coast area. The studies are designed to solve urgent problems when the need is greatest and to provide hydrologic data for areas where problems are incipient or inevitable. In the first category are studies, largely quantitative, of artificial recharge, sustained yield, surface- and ground-water relations, chemical and physical quality, well-field development, and flow forecasting. Included in the second category are areal ground-water appraisal studies, observation-well and gaging-station networks, reconnaissance sediment and chemical-quality determinations, estimated sustained-yield studies, and peak-discharge observations.

ALASKA

An important aspect of the water-resource program in Alaska concerns the development of water supplies for communities and military installations. Although surface water is available at many places and in abundant quantity, winter freezeup of streams renders its year-round use impracticable in many parts of the State. Although ground water can satisfy much of the domestic and municipal demand, even this source of supply has limitations. Where the ground is perennially frozen, in many places to great depths, obtaining any firm water supply may be difficult or impossible. The program of the U.S. Geological Survey encompasses a hydrologic data-collection network, including sampling for sediment load, on many of the streams as a basis for flood-frequency studies, and for the evaluation of streams for waterpower potential. The Geological Survey also makes investigations of the chemical character of ground and surface waters. Some effects of the Alaskan earthquake of March 27, 1964, involving water facilities are described in the section on "Alaskan Earthquake."

Summary of water resources

In a report on the statewide water resources, A. O. Waananen and G. C. Giles (U.S. Geological Survey, 8–64) show that Alaska has enormous resources of water and power that are still at a very early stage of development. Alaska, with an estimated 17 million kilowatts of waterpower at potential and developed sites, ranks second only to Washington, among the States, in this resource. Installed waterpower facilities in Alaska produced 76 megawatts of power in 1960 and used about 410,000 acre-feet of water—about half of 1 percent of the resource estimated to be available.

Public water supply sought at Angoon

W. N. Lockwood (1–64) finds that not enough ground water could be developed from steeply dipping marble and schist at Angoon to meet the demands of the village. Of 3 wells drilled, 1 was dry and the other 2 yielded 1 gallon per minute or less. Possible alternate sources of supply include (1) ground water in buried beach gravels under muskeg swamps, (2) ground water in deposits of Eocene age on Favorite Bay, and (3) impoundment of surface water in a tidal flat near Killisnoo.

Ground-water supply at King Salmon found adequate

A. J. Feulner (1–63) reports that an adequate supply of ground water is available at the village of King Salmon and the U.S. Air Force station there. Supplies of water in excess of 100 gallons per minute can be developed from wells that tap aquifers in the outwash-plain deposits that underlie the village to a depth of 300 feet or more. Existing wells that range in depth from 97 to 228 feet below land surface yield as much as 100 gpm.

PACIFIC NORTHWEST

The Pacific Northwest comprises the States of Idaho, Oregon, and Washington. Within this area is included most of the drainage basin of the Columbia River, and the Puget Sound lowland, which is an area of potentially great industrial development. Although the Pacific Northwest, as a whole, has enough water to support the area's anticipated development, numerous water-resource problems are evident. These include unbalanced areal development of surface-water and ground-water potential, water logging, conflicts in water use, and pollution of streams and shallow ground-water bodies. The Geological Survey program in the region includes studies of chemical and physical properties of water, (see also "Distribution of Minor Elements as Related to Public Health") occurrence and distribution of ground water, low flow of streams, the effect of denudiation on streamflow and sediment content, and probable future base flow. The location of water supplies in national parks, Indian reservations, and at military installations is a significant part of the program.

Springs common in Columbia River Basalt

The layered arrangement of the permeable interflow zones in the Columbia River Basalt and the relatively low permeability of the rock elsewhere result in many permanent springs, even where the annual precipitation is only 10 inches. According to R. C. Newcomb those springs give much of the region a fairly good and widespread supply of water for stock and wildlife, in contrast to the inhospitable deserts where similar amounts of rain falls on the highly permeable and sievelike lavas of some of the Pleistocene volcanic rocks elsewhere in the Pacific Northwest.

Ground-water supplies adequate in Thurston County, Wash.

On the basis of an appraisal of ground-water resources in Thurston County, Wash., J. B. Noble and E. F. Wallace report that throughout much of the populated parts of the county, enough water can be supplied from wells to satisfy most or all the municipal and rural domestic and irrigation demand. Virtually all the ground water now developed or capable of development occurs in glacial or interglacial permeable deposits of Pleistocene age. Locally along the shore of Puget Sound, salt-water intrusion has occurred and water from a few wells is affected. In the upland part of the county, where rocks of Tertiary age are exposed or are near the land surface, attempts to develop water have met with little success; these rocks are of low permeability almost everywhere and the ground water is, in general, of poor quality.

Ground-water yield of Spokane River basin

In a study of the usable-water yield of various components of the Spokane River basin, R. L. Nace shows that the ground-water yield of this basin east of Spokane is equivalent to a continuous flow of 1,00 cubic feet per second.

Exceptional spring discharge to Green River, Wash.

In a study of water resources in King County, Wash., J. E. Luzier and Donald Richardson measured an exceptionally large amount of discharge from springs into the bedrock gorge of the Green River near Black Diamond, Wash. Springflow along an 11-mile section of the gorge is as much as 175,000 gallons per minute during the winter, decreasing to about 2,000 gpm during the summer. About half the discharge is from four springs; many small springs and seepage zones account for the remainder. A thick and areally extensive deposit of glacial outwash through which the Green River has carved its course is the principal ground-water reservoir.

Conserving stock water in Oregon

In a reconnaissance of stock-water resources in the Lakeview Grazing District in southern Oregon, F. F. Zdenek found that long narrow pits dug in small ephemeral lakes provide an effective means of storing small amounts of runoff. These pits hold water during most of the summer, much longer than most shallow basins, and permit the use of grazing land and forage that otherwise would be wasted. Construction of these pits are suggested for remote areas where development of ground water through wells is not feasible.

Summary of water resources in Idaho

In a summary on statewide water resources, W. I. Travis, H. A. Waite, and J. F. Santos report that although Idaho is generously supplied with water, there is considerable maladjustment of supply and demand, both areally and in time. Average annual inflow is 32.4 million acre-feet and outflow is 66.5 million acre-feet—

a contribution to downstream areas of 34 million acre-feet. About 2.6 million acre-feet of ground water was withdrawn in 1960 as the sole or principal supply for irrigation of more than 800,000 acres of land. Nearly 3 million acres are irrigated in the Snake River basin of Idaho and Oregon. Most of the water resources are suitable for irrigation, and for most other uses only a minimum of treatment is needed.

Spring contribution to Snake River declining

C. A. Thomas reports that the Snake River between the gaging stations at Milner, Idaho, and King Hill, Idaho, has gained more than 7,500 cubic feet per second on the average during the period 1910–62. The gain is largely from scores of springs within a 46.5-mile reach along the north bank, which discharge water from an aquifer beneath the Snake River Plain. The aggregate flow of the 21 springs was 3,380 cfs in 1902, 5,380 cfs in 1956, and 4,300 cfs in 1962. Based on correlation with total inflow between the Milner and King Hill gaging stations, the discharge of the springs increased markedly from 1902 to 1917, probably as a result of irrigation on the Snake River Plain. The discharge increased at a lesser rate from 1917 to 1946, remained relatively steady from 1946 to 1959, and then declined in the period 1959 to 1962. The decline since 1959 indicates that increased pumpage from the aquifer has more than offset the effect of factors that tend to increase discharge.

Precipitation and evapotranspiration in Malad River basin

Studies by R. L. Nace and E. J. Pluhowski in the Malad River basin, Idaho, indicate that the annual precipitation ranges from about 15 inches in the lowlands to 30 inches or more in the highest areas and that potential evapotranspiration ranges from about 24 inches on the floor of the basin to 16 inches in the highlands. The average lapse rate was computed to be 2.7°F per 1,000 feet.

NEVADA

The principal water-resource problems in Nevada are attributable to the relatively small natural supply available to the State. For the State as a whole, the average annual precipitation is less than 9 inches; of this amount, probably less than 8 percent becomes available either as surface-water runoff or as recharge to the valleys. Among the problems are maldistribution of supply, flood damage, low yield of aquifers in some places, water use by phreatophytes, and loss from surface-water bodies by evaporation. According to Nevada ground-water law, if depletion of a ground-water basin is imminent, the State Engineer is empowered to establish necessary regulatory measures for control of the ground-water basin for sound conservation and the best interests of the public welfare. The U.S. Geological Survey is attempting to supply hydrologic information at a rate that will permit effective management of the State's water resources. An important part of the program is the continuing basic-records inventory for both surface and ground water. Basin or valley studies are categorized as reconnaissance, areal, comprehensive, and specific-problem studies. In sequence, they represent successive stages of work intensity for a given area.

Summary of water resources

In a statewide report on water resources of Nevada, H. E. Thomas points out that 93 percent of the State's population live in the 20 percent of the State having the largest perennial sources of water. The rest of the State has a population density considerably less than one person per square mile. Conservation of water in surface reservoirs in the more arid parts of Nevada involves great evaporation losses. Evaporation from Lake Mead, for example, is 3 times as great as the quantity of Colorado River water allocated to Nevada. The preponderant proportion of all the water stored in Nevada is ground water—a volume many times as great as the gross supply received annually by precipitation.

Estimates of ground-water yield in desert basins

Statewide ground-water reconnaissance studies in Nevada by T. E. Eakin, W. C. Sinclair, Philip Cohen, F. E. Rush, D. E. Everett, and E. G. Crosthwaite provided preliminary estimates of recharge, discharge, and (or) perennial yield for 15 ground-water basins. The preliminary estimates of perennial yield, which provide a management guide, are evaluated from estimates of natural recharge to and discharge from particular ground-water basins.

Preliminary estimates of perennial yield for 10 of the ground-water basins studies are: 14,000 acre-feet in Middle Reese River valley, and 9,000 acre-feet in Antelope Valley, Lander County; 40,000 to 50,000 acre-feet for nine basins tributary to the Black Rock Desert, Pershing and Humboldt Counties; 6,000 acre-feet in Virgin Valley, 3,000 acre-feet in Gridley Lake valley, 11,000 acre-feet in Continental Lake valley, and 2,000 acre-feet in Pueblo Valley, Humboldt County; 18,000 acre-feet in the Dixie-Fairview Valley area, Churchill and Pershing Counties; 12,000 acre-feet in Lake Valley, Lincoln and White Pine Counties; and 27,000 acre-feet in the Meadow Valley area, Lincoln and Clark Counties.

Interbasin movement of ground water

Reconnaissance investigations in several topographically closed valleys in the southeastern part of Nevada indicate that estimated replenishment and discharge are not in balance. (See also "Nevada Test Site Studies.") T. E. Eakin (1, 2, 3–63) finds that most of the discharge occurs by underflow from one valley to another through Paleozoic carbonate rocks. Estimates of annual recharge to valleys having interbasin movement of ground water are: 6,000 acre-feet to Dry Lake and Delamar Valleys, Lincoln County, and 12,000 acre-feet to Garden and Coal Valleys, Lincoln and Nye Counties.

Eakin estimates that the recharge from precipitation within Pahranagat Valley is only about 1,800 acre-feet per year, although natural discharge is at least 25,000 acre-feet per year. The excess discharge is supplied by underflow from the surrounding valleys to the north, northeast, and possibly northwest.

Ground-water barrier prevents interbasin movement

Field determinations of specific conductance, hardness, pH, and iron show a marked difference in chemical character between water in the playa deposits in Rhodes Valley, Mineral County, and that in the alluvial deposits of Soda Spring valley to the north, according to C. T. Snyder. This evidence, coupled with that provided by trends in chemical character of the ground water, suggests strongly that there is a barrier between the two valleys that effectively prevents ground-water movement between them.

CALIFORNIA

One of the most troublesome water problems in California is the inequitable distribution of supply. In the southern part of the State, where the demand is greatest, the supply is deficient, while the supply is abundant in the northern part of the State, where demand is light. Other outstanding problems are land subsidence, changes in runoff resulting from urbanization, uncontrolled transpiration by phreatophytes, and sea-water intrusion in coastal water supplies. A significant part of the water-resources program in California is the collection and publication of basic hydrologic data. Included is a continuing series of measurements of streamflow, water levels in wells, chemical quality of water, and sediment in streams and reservoirs. Areal interpretive studies are being made in many parts of the State. Examples of these are the comprehensive appraisal studies in Santa Barbara County, in Antelope Valley, and in the San Joaquin Valley.

Urban growth increases volume of storm runoff at Mountain View

Urban development has greatly increased the volume of storm runoff produced by rainfall in the city of Mountain View, Santa Clara County, according to E. E. Harris and S. E. Rantz (1–63). The hydrologic effect of urban growth was studied in a 5-square-mile area that is drained by Permanente Creek and its tributary, Magdalena Creek. Both creeks have permeable streambeds through which water seeps to recharge the underlying ground-water body. In 1945, when the greater part of the study area was orchard, and only 4 percent of the area was covered by impervious surfaces such as roofs and pavements, the volume of local storm runoff was consistently less than the seepage capacity of the channel. The ratio of the total outflow from the area to the streamflow entering was 1.18. By 1958, urban development had reached the stage where 19 percent of the study area had been made impervious. As a result of this increase in impervious surface, the ratio of total flow to inflow rose to 1.70, indicating about a fourfold increase in local storm runoff since 1945.

Interbasin movement of ground water in northeastern California

Drainage basins between the Warner Range to the east and the Cascade Range to the west are underlain by vesicular, blocky lava flows of Pleistocene and Recent age. These flows are, in turn, underlain by relatively impermeable lava flows of Miocene and Pliocene age. According to R. H. Dale, the flows of Miocene age, exposed in both the Warner and Cascade Ranges, form effective barriers that prevent the eastward or westward migration of ground water. Water levels in wells tapping the permeable lava flows of Quaternary age that underlie the intermontane basins show that ground-water movement is generally southward, from basin to basin. For this reason, ground-water divides, if they exist, do not necessarily coincide with the low topographic divides that separate individual basins.

Artificial-recharge study in San Joaquin Valley

Preliminary results of detailed studies by R. W. Page indicate that parts of the east slope of the San Joaquin Valley between the San Joaquin and Kings Rivers would be insuited for artificial recharge by water spreading where the slope is underlain by poorly sorted, poorly permeable material, or by extensive clay beds. Except in the area of the Kings River, poorly permeable material extends valleyward about 6 miles from the crystalline bedrock foothills of the Sierra Nevada, and extensive clay beds underlie a belt about 4 miles wide, east of the trough of the San Joaquin Valley.

Ground-water supply for Mission Creek Indian Reservation

A reconnaissance investigation of ground-water conditions on the Mission Creek Indian Reservation by J. W. Giessner (1-64) shows that a small supply probably could be developed from shallow wells. Mission Creek, the principal stream of this part of the south slope of the San Bernardino Mountains, crosses the reservation, and ground-water storage in the permeable gravel beneath the intermittent stream probably is sufficient to sustain a modest amount of pumping each season.

Quality of ground water in Santa Ynez River basin

Analyses of water from irrigation wells in the Lompoc subarea of the Santa Ynez River valley, sampled periodically since 1934, suggest deterioration in chemical character of ground water. R. E. Evenson reports that the deterioration in some places is caused by an increase in chloride content and in others by an increase in both chloride and sulfate content. In general, the deterioration attributable to increase in chloride is believed to result from mixing of ground water with connate water from marine sediments. Deterioration characterized by increases in both chloride and sulfate may be due to recycling of irrigation water.

Salt-water intrusion in Santa Maria coastal basin

Overdraft of the Santa Maria coastal ground-water basin since about 1940 has resulted in a significant decline in water levels throughout the basin as ground water has been removed from storage. Estimates by G. A. Miller and R. E. Evenson of storage depletions are not consistent with estimates of ground-water recharge and discharge. The discrepancy can be accounted for largely by movement of the fresh water-sea water interface at the offshore end of the aquifer system in response to the continued inland decline of head.

Natural barrier protects ground-water supplies at Santa Barbara

Studies of ground-water supplies in the Santa Barbara city area by K. S. Muir indicate that ground water in storage is protected from sea-water intrusion by an offshore barrier, probably a fault of considerable lateral extent and considerable vertical displacement. This barrier extends at least as far as Carpinteria, 10 miles easterly, and there, too, is an effective natural barrier marking the offshore submarine truncation of the fresh-water aquifers.

HAWAII

Among the vexing water-resource problems in Hawaii are sea-water intrusion, the effect of recurring volcanic activity on the ground-water body, and local overpumping. Water-resource studies include investigations of the base-flow characteristics of streams and their relation to ground water, the amount of precipitation that can be collected from artificial catchments, and drainage-basin yield. Basic data of many different types are being collected. Probably the most unusual are the records of precipitation at the site of the highest known mean annual rainfall in the world, and records of wave action in Hilo harbor.

Water supply for Kau area is adequate

The water supply of the Kau area of the island of Hawaii appears to be sufficient for normal needs, according to D. A. Davis and G. Yamanaga. Although the average annual rainfall is 125 inches or more in an area of 6 to 10 miles inshore, there is no perennial surface flow to the ocean. There are, however, large springs along the coast that discharge fresh and brackish water. Of those that discharge fresh water, the largest is between Punaluu and Honuapo; its visible discharge ranges from 30 to 50 million gallons per day. Pumpage from the aquifer that yields water to this spring is less than 3 million gallons per day. Perched water is developed through numerous tunnels. The aggregate yield ranges from 1 to 8 mgd. High-level water is impounded at a height of 230 feet above sea level and is drawn on at a rate of about 1.5 mgd.

Tunnel discharge related to precipitation on Oahu

C. P. Zones finds a near-linear relation between rainfall and discharge from ground-water tunnels in the Waianae district of Oahu. A plot of cumulative tunnel discharge against cumulative precipitation is a straight line whose slope is a measure of the tunnel discharge per unit amount of rainfall. A long-term change in tunnel discharge relative to rainfall is indicated by a change in slope. This type of plot, or double-mass curve, is being used to evaluate the effects of new ground-water development on the quantities of water discharged from existing tunnels.

Several tunnels were constructed near the head of Waianae Valley in about 1900, and two others were built several years later. Graphical analysis of tunnel discharge shows that each time a new tunnel was built, a new equilibrium between tunnel discharge and rainfall was established in less than 5 years. Although discharge of the combined tunnels increased after each new tunnel was built, the yield of preexisting tunnels declined.

Ground-water draft in Kahuku area, Oahu

The Kahuku area, Oahu, includes 61 square miles of the northern end of the Koolau range and of its bordering coastal plain, which consists of extensive marshes and large irrigated areas. The average annual rainfall over the 61-square-mile area is 84 inches or about 273,200 acre-feet per year. K. J. Takasaki finds that the average annual ground-water draft is about 33,000 acre-feet (30 million gallons per day) or roughly 12 percent of the rainfall. Perennial surface-water flow is small and is not utilized. Between 20 and 25 percent of the rainfall flows into the sea as runoff during and after heavy rains. On the basis of preliminary data the average evapotranspiration is estimated at 50 to 60 percent of the rainfall. It is less than 5 percent in the high-rainfall areas and is more than 250 percent in the windy, low-rainfall coastal plain.

SALINE WATER RESOURCES

Mapping saline ground-water resources of the United States

Saline ground water is considered as a natural resource, not a problem, in a map of the 48 conterminous United States prepared by J. H. Feth and others.[30] The map illustrates the shallowest known occurrences of saline and slightly saline ground water. Concentration ranges of dissolved solids illustrated are 1,000–3,000 parts per million, 3,000–10,000 ppm, 10,000–35,000 ppm, and more than 35,000 ppm. Areas inferred to have saline ground water, though no wells have been drilled that encounter it, are also shown. Depth from land surface to the shallowest saline-water occurrence is illustrated in the ranges of less than 500 feet, 500–1,000 feet, and more than 1,000 feet. Investigations of saline waters that pose a threat to fresh-water supplies are reported under the section "Water Contamination Studies."

Saline ground water of Michigan

A study of the saline ground-water resources of Michigan by J. R. Rapp and K. E. Vanlier indicates relatively large supplies of saline ground water in the State. This saline water occurs in Paleozoic bedrock underlying glacial drift, which nearly everywhere contains fresh ground water. In the central upland areas the high head of fresh water depresses the fresh-water–saline-water interface considerably below the level of Lakes Michigan and Huron. In the lowland areas adjacent to the Great Lakes and along some inland streams, there is little fresh-water head and the interface is shallow. Saline water is discharged into lakes and streams in a few places where the interface is above the level of the stream or lake. The discharge of saline water is facilitated by the basin structure of the bedrock formations which allows the water to move updip from the center of the basin to the lowland areas. The salinity of well water increases in areas of large-scale ground-water development where the fresh-water head has been lowered by pumping. Brine is produced for industrial use in many places in the Lower Peninsula.

[30] J. H. Feth, compiler, 1964, Resources of mineralized ground water in the conterminous United States: U.S. Geol. Survey open-file rept.

Saline ground water of Utah

Ground water ranging from slightly saline (1,000–3,000 parts per million of dissolved solids) to brine (greater than 35,000 ppm of dissolved solids) occurs in many parts of the Basin and Range, Colorado Plateaus, and Middle Rocky Mountains physiographic provinces in Utah, according to C. A. Horr and others. In the Uinta Basin, lake deposits of Paleocene or Eocene age, and parts of the Mesa Verde, Uinta, Green River, and Duchesne River Formations and the Mancos Shale contain saline water with a dissolved-solids content of from 1,000 to 10,000 ppm. In southeastern Utah the Mancos Shale and the Mesa Verde and Morrison Formations produce small amounts of water containing from 1,000 to 10,000 ppm of dissolved solids. Locally, the San Rafael Group and Glen Canyon Group produce similar water. The underlying Paradox Formation contains water with dissolved solids exceeding 35,000 ppm. Scattered occurrences of slightly saline water are found in rocks of Jurassic, Cretaceous, and Tertiary age along the northern flank of the Uinta Mountains.

Most of the saline ground-water resources within the State occur in the alluvial valleys in the Great Basin. The saline water in these areas is derived from Lake Bonneville beds and older deposits of Tertiary and Quaternary age and ranges in salinity from 1,000 to over 200,000 ppm of dissolved solids. In general the freshest water is found near the flanks of these valleys and grades into water containing 3,000 to 10,000 ppm of dissolved solids in the lower parts of the valleys. The Great Salt Lake Desert would probably yield ground water having more than 3,000 ppm of dissolved solids. In the Bonneville Salt Flats area there are known occurrences of ground water containing over 200,000 ppm of dissolved solids.

Saline ground water of California

Studies by J. S. Bader (1–64) indicate large supplies of saline ground water throughout much of California. Ground water containing more than 1,000 parts per million of dissolved solids occurs in about 30 alluvium-filled valleys in the desert area of southern California. Other bodies of saline ground water occur in the San Joaquin Valley and in several other smaller basins as far north as the Oregon border.

Wells in these areas are seldom completed and developed when they tap bodies of saline water. Even when completed, the wells are frequently short-lived because of the corrosive action of the water on well casings, screens, and pumping equipment. However, as the need for water increases and as techniques for desalination are perfected, the large supplies of saline water will become available as a water resource in areas previously considered uninhabitable because of the lack of fresh water.

MANAGEMENT OF NATURAL RESOURCES ON THE PUBLIC LAND

An expanding economy for the future is dependent upon wise management of the resources of the Nation. The public lands contain a significant portion of these resources, and responsibility for management of the land and use of the resources is exercised by several agencies of the U.S. Government. The U.S. Geological Survey, through its Conservation Division, classifies these lands for such resources as leasable minerals and sites for waterpower projects, and supervises the prospecting, development, and recovery of certain minerals from wells and mines under lease, permit, or license on Federal and Indian lands. Contribution from the Federal lands to total mineral production of the United States is shown on figure 4.

The classification functions of the Conservation Division are performed by the Branch of Mineral Classification and the Branch of Waterpower Classification. The supervisory functions are performed by the Branch of Mining Operations and the Branch of Oil and Gas Operations. The Conservation Division also supervises the administration of the Connally Act of February 22, 1935.

Field offices of the Division are listed on page A227. Geologic and hydrologic work in progress by geologists and engineers of the Conservation Division is given in the list of investigations starting on page A233, under the categories of geologic mapping, glaciology, waterpower classification, and various commodities such as coal and petroleum and natural gas. Scientific and economic results of these investigations are published as books and maps in the regular series of Geological Survey publications.

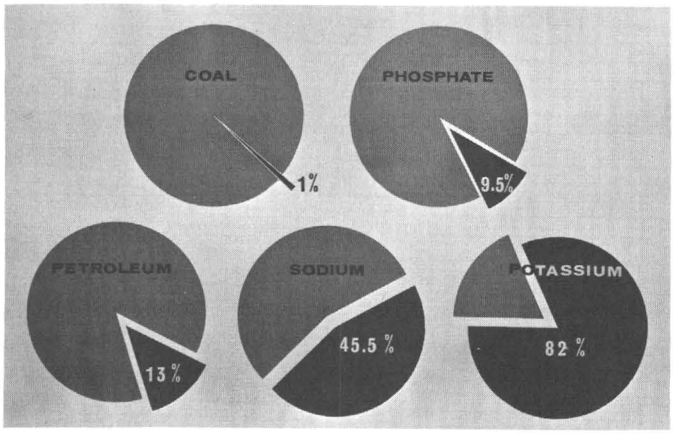

FIGURE 4. Percentage of total United States mineral production that comes from Federal land.

CLASSIFICATION OF MINERAL LANDS

The principal leasable minerals are oil, gas, oil shale, coal, phosphate, sodium, and potash. Since 1906, public lands believed to contain leasable minerals have been withdrawn from entry by the Secretary of the Interior, on the advice of the Geological Survey, pending their classification as mineral or nonmineral lands. At present about 41 million acres of land is so withdrawn.

In order to classify land for its mineral value, the geology must be mapped in detail, usually at a scale of 1:24,000. Existing geologic maps are used where of suitable quality and scale. Mapping for mineral-land classification differs in some details from general geologic mapping in that more measurements of stratigraphic sections per quadrangle are required to show thicknesses of coal or other leasable minerals, and more frequent sampling is necessary to determine mineral quality. Drill-hole cuttings or cores and electric or radioactivity logs provide subsurface data for classification. Samples obtained from surface and subsurface operations are analyzed in the laboratory. When the areal extent, thickness, and grade of mineral deposits are established, the land containing them is classified as to its value for mineral resources. The geologic maps produced for classification purposes are published in the standard map series of the Geological Survey.

WATERPOWER CLASSIFICATION

Classification of public lands to conserve and utilize water resources was begun in 1888, to preserve reservoir sites for irrigation. It has been continued chiefly for hydroelectric development. Present activity includes stream-basin investigations, a review of land classifications and reserves, and the measurement of selected glaciers.

The program of stream-basin investigations is a systematic search for basins and subbasins where water projects can be developed in the future to serve the needs of a growing population. Sites that meet the criteria for classification are set aside by the Secretary of the Interior on the recommendation of the Geological Survey, through procedures established by Congress and the Department of the Interior. Land set aside by these procedures may be disposed of only according to procedures which provide that it may be reacquired by the Government for purposes of waterpower development without cost.

A program to reassess all land classifications and reserves was begun in 1956. Many classifications and reserves had been made before 1920 under Congressional and departmental urging for immediate protection of sites for waterpower development. Because of this urgency many of the classifications were based on inadequate map and hydrologic data. Under the present program all reserves are being reevaluated and classified by rigorous standards. Lands that do not qualify as waterpower sites are removed from the reserves and are opened to disposition under the public-land laws. Progress through fiscal 1964 on this program indicates that as much as 50 percent of lands now reserved for waterpower may eventually be eliminated from the reserves.

River and lake basins are mapped mostly at a scale of 1:24,000. Contours of lake bottoms are compiled by precise sounding surveys. The results of investigations are published as special maps and sheets.

A special project to gather information on the rates of ablation and the recession or advance of selected glaciers was started in 1941 on Nisqually Glacier in Mount Rainier National Park, Wash., and in 1944 on Grinnell and Sperry Glaciers in Glacier National Park, Mont. Annual measurements are made at monumented cross sections, and the glaciers are mapped completely at 5-year intervals. In 1961, at the request of and in cooperation with the Bureau of Reclamation, measurements were begun on Barrier Glacier, Mount Spurr, Alaska, to determine what effect the growth or shrinkage of the glacier has on fluctuations in the level of Lake Chakachamna.

SUPERVISION OF PROSPECTING, DEVELOPMENT, AND RECOVERY OF MINERALS

Supervision of operations under mineral leases entails the investigation of lands and deposits under application for mineral leases, oil and gas leases, and prospecting permits; recommendation of lease terms and unit areas; enforcement of operating regulations and measures to assure the safety and welfare of workmen; maintenance of production records; and determination and collection of royalties and rentals. The mineral supervisory branches of the Conservation Division also act as advisors to the Secretary of the Interior, to other bureaus of the Department, and to other Government agencies concerned with the administration of the Mineral Leasing Laws.

Royalties from public lands are distributed 52½ percent to the Reclamation fund, 37½ percent to the States in which the minerals or fuels are produced (except for Alaska, which receives 90 percent), and 10 percent to the Federal Treasury. Royalties from other land categories are distributed in many different ways as provided by law, but the largest share of these royalties is returned directly to the Federal Treasury.

Mining operations

The Branch of Mining Operations supervises operations concerned with discovery, development, and production of coal, oil shale, phosphate, potassium, solid and semisolid bitumin, and sodium from public land; and of sulfur from public land in Louisiana and New Mexico. The branch also supervises the production of silica sand on certain lands in Nevada; mercury on certain Spanish land grants; all minerals except oil and gas on restricted, allotted, and tribal Indian lands; and all minerals recoverable in commercial quantities, except oil and gas, on acquired lands.

The following table shows production of minerals and royalties received from leased Federal lands under supervision of the Branch of Mining Operations for the fiscal year ending June 30, 1964.

Land category	Production (tons)	Value (dollars)	Royalty (dollars)
Public	22, 693, 000	159, 809, 000	6, 677, 000
Acquired	164, 000	2, 309, 000	92, 000
Indian	7, 713, 000	22, 964, 000	2, 234, 000
Total	30, 570, 000	185, 082, 000	9, 003, 000

Oil and gas operations

The Branch of Oil and Gas Operations supervises the discovery, development, and production of crude oil and natural gas and associated products from leased public, acquired, Indian, Outer Continental Shelf, and Naval Petroleum Reserve lands. About 12 percent of United States oil production in 1962 came from leases on Federal lands.

The following table shows the production of crude oil, the value of petroleum products, and the royalties received from supervised leases on the various categories of Federal and Indian lands during fiscal 1964.

Land category	Oil production (barrels)	Gas production (million cu ft)	Liquid petroleum gas (gallons)	Value (dollars)	Royalty (dollars)
Public	177, 800, 000	573, 700, 000	433, 600, 000	567, 700, 000	72, 180, 000
Outer Continental Shelf	114, 200, 000	566, 800, 000	------------	456, 100, 000	81, 260, 000
Acquired lands	5, 510, 000	77, 240, 000	1, 360, 000	20, 550, 000	2, 585, 000
Military and miscellaneous	2, 510, 000	74, 410, 000	80, 600, 000	21, 860, 000	4, 506, 000
Naval Petroleum reserves	4, 180, 000	6, 200, 000	13, 500, 000	15, 190, 000	1, 938, 000
Indian	42, 100, 000	106, 400, 000	158, 300, 000	133, 310, 000	17, 510, 000
Total	346, 300, 000	1, 404, 750, 000	687, 360, 000	1, 214, 710, 000	179, 979, 000

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND PUBLIC HEALTH

A substantial part of the effort of the U.S. Geological Survey is directed toward specific application of geology and hydrology to engineering and public health. Major activities include (1) investigations on behalf of the U.S. Atomic Energy Commission of the geology and hydrology of underground nuclear explosions and disposal of radioactive waste; (2) studies of contamination of water supplies and of the distribution of mineral matter as related to public health; and (3) investigations of geology and hydrology related to engineering problems in construction (including those activities related to nuclear-power reactor sites), mining, water management, and flood control. A timely special activity this year was a study of the geologic aspects of the Good Friday earthquake in Alaska on March 27, 1964.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

Underground nuclear explosions and the generation of power by nuclear reactors release radioactive products to the geologic and hydrologic environments. In order to safeguard the public, the distribution, movement, and concentration of these products must be determined and the potential public hazard evaluated. In addition, the engineering and construction of facilities for underground nuclear explosions and nuclear reactors pose unique and difficult problems requiring a thorough knowledge of geologic and hydrologic conditions in a variety of natural environments. Since 1956 the U.S. Geological Survey has provided geologic and hydrologic data on the environment of reactor and underground test sites at the Nevada Test Site, and at sites for the PLOWSHARE (peaceful uses of nuclear explosions) and VELA UNIFORM (detection of underground nuclear explosions) Programs, and has evaluated these data for the Atomic Energy Commission.

During 1963, intensive geologic and hydrologic studies were carried on because of continued underground testing of nuclear devices, increased interest in the peaceful application of nuclear explosions, continued experimentation in the detection of underground explosions, and experimentation leading to the development of nuclear energy for space engines.

Hydrologic studies of disposal of radioactive wastes focused chiefly on transport of radioactive materials in streams, particularly in the Columbia and Tennessee River basins; development of acceptable methods of disposing of wastes to the ground; and evaluation of hazards to water supplies from proposed nuclear reactor plants.

NEVADA TEST SITE STUDIES

Investigations during 1963 at the Nevada Test Site were concentrated on (1) the geologic history and structure of the Timber Mountain and Black Mountain calderas; (2) a geologic-hydrologic appraisal of the Pahute Mesa underground test area; (3) geologic reconnaissance of the region north of the Nevada Test Site; (4) definition of test media and evaluation of the effects of underground nuclear tests in Yucca Flat; (5) interpretation of the subsurface geologic structure of the Nevada Test Site, using gravity and aeromagnetic data; (6) hydrologic studies of the regional groundwater regimen and the effects of a nuclear explosion below the water table; and (7) investigation of the ion-adsorption properties of various rock types used as testing media.

During the year, the first 3 geologic quadrangle maps (Tippipah Spring, Oak Spring, and Rainier Mesa), of a projected total of 33 maps for the Nevada Test Site, were published (Orkild (1–63); Barnes, Houser, and Poole (1–63); Gibbons, Hinrichs, Hansen, and Lemke (1–63)). Also published was a report describing the geologic setting of the first underground nuclear explosion—the RAINIER explosion (Hansen and others, 1–63).

Timber Mountain and Black Mountain calderas

Geologic mapping has made possible reconstruction of the detailed history of the Timber Mountain caldera and a tentative history of the Black Mountain volcanic center.

The wall of the Timber Mountain caldera can be defined reasonably well: it consists of highly fractured pre-caldera tuffs overlain unconformably at many places by tuff probably ejected from beneath the caldera area. Within the caldera, potassium-argon age determinations indicate that the tuffs of Cat Canyon, which form a dome structure, are only slightly older than the tuffs of Ammonia Tanks, which are distributed circumferentially around the caldera on radii as great as 25 miles. Petrographic and chemical analyses indicate that the tuffs are genetically related. The geographic limits of some of the tuffs related to the caldera are incompletely known, but some have been traced southwestward to the California-Nevada boundary, south into the Amargosa Desert, north and northwest to Gold Flat, and east to Paiute Ridge. Dikes of intrusive tuff occur in the inner ring-fracture zone of the caldera and range from a few inches to several tens of feet in width. The dikes are believed to be correlative with one of the uppermost cooling units of the tuffs of Timber Mountain.

The Black Mountain area, on Pahute Mesa, 25 miles northeast of Beatty, Nev., was a Pliocene volcanic center which erupted a suite of chemically and petrographically distinctive rocks with alkalic affinities. The volcanism is characterized by the successive formation of central volcanoes of intermediate to rhyolitic lavas followed by periods of voluminous rhyolitic ash-flow eruptions. The extent and thickness of rocks produced in each of these eruptive cycles indicate that the volcanism commenced abruptly and continued in episodes of progressively decreasing intensity. Following each major period of ash-flow eruption, the summit area of the preceding volcano collapsed to form a caldera with a major diameter of about 9 miles. Each succeeding group of lavas filled or partly filled the earlier caldera, but the ash flows spread widely to form the welded to nonwelded Thirsty Canyon Tuff (Noble and others, 4–64). The last ash flows were of small volume and were not followed by caldera collapse.

Pahute Mesa

The complex geology of Pahute Mesa has required the fullest use of many geologic techiques in the evaluation of the mesa as a test area. Drill-hole information indicates that the mesa is made up of more than 13,000 feet of volcanic rocks that were derived from at least four different source areas. Geologic maps by E. B. Ekren and others, and gravity maps by D. L. Healey and C. H. Miller (1–63) have provided the data for the selection and exploration of test sites. In addition, remanant magnetism studies by G. D. Bath, in conjunction with aeromagnetic maps, have delimited the distribution of buried rhyolite lava flows of high water yield. From surface data, K. A. Sargent has identified more than 12 separate rhyolite flows on the basis of their heavy-mineral content.

Reconnaissance north of the Nevada Test Site

A reconnaissance of the area north of the Nevada Test Site was made to obtain regional geologic information for use in evaluating possible test areas. The Pahute Mesa test area was selected on the basis of information obtained from this reconnaissance.

A byproduct of geologic mapping of 2,000 square miles north of the Nevada Test Site by E. B. Ekren, R. E. Anderson, C. L. Rogers, D. C. Noble, and Theodore Botinelly was the recognition of the possibility of buried mineralized areas. Hydrothermal alteration and weak precious-metal mineralization are widespread in the older volcanic rocks, which include lavas and intrusive masses of intermediate composition and which appear to be of the same type as host rocks of ore deposits at Goldfield, Nev. An ash-flow sheet of Pliocene age, the Thirsty Canyon Tuff, which throughout most of its areal extent averages less than 100 feet in thickness, was extruded on an erosional surface of considerable topographic relief and thus partly blanketed the older strata. Areas that were topographically high during Thirsty Canyon time and were not covered by the tuff are topographically high today. The high areas include the hills around Goldfield, the only area that to date has been extensively prospected. There is a good possibility that some ore deposits are concealed by the Thirsty Canyon Tuff.

Another byproduct of the reconnaissance was the discovery of an ash-flow tuff unit with a higher than average beryllium content, the Gold Flat Member of the Thirsty Canyon Tuff, which contains as much as 60 parts per million of beryllium.

Yucca Flat

Study of surface and subsurface geologic information from continued drilling in Yucca Flat is resulting in a detailed three-dimensional analysis unique in the Basin and Range province. Significant changes in thickness and extent of some rock units have been delineated, and this knowledge, together with structural information, has been used to relocate and (or) redesign certain experiments. The detailed information is also providing a basis for a more efficient use of Yucca Flat as a test area.

Nuclear explosions in Yucca Flat have caused renewed movement along Yucca fault, a regional structure, and have developed fractures parallel to local structural features.

Structural and stratigraphic control of interbasin movement of ground water

A recently completed map of the potentiometric surface of confined water in Paleozoic aquifers at the Nevada Test Site indicates a remarkable correspondence with certain elements of the regional structure and stratigraphy of the Paleozoic rocks. The map lends support to an early hypothesis that the Paleozoic clastic rocks act as "ground-water dams" and are also, in effect, the "hydraulic basement," with respect to interbasin movement of water. The map suggests that the outcrop pattern of the clastic rocks may be utilized in some basins to determine the dominant direction of interbasin ground-water movement in the principal aquifer—the Paleozoic carbonate rocks.

Geophysical studies

Geophysical techniques, particularly gravity and magnetic surveys, are useful in delineating subsurface distribution of igneous bodies and in the correlation of lava flows. An example of the application of the gravity method to determine the shape of an igneous body is reported by D. L. Healey and C. H. Miller (1–63) for the Gold Meadows stock.

Field and laboratory measurements of remanent magnetism by G. D. Bath are proving to be a valuable aid for correlation of volcanic rocks as well as for the interpretation of aeromagnetic maps. No lateral variations in the polarity of remanent magnetism have been found in the welded-tuff cooling units tested, some of which have an areal extent of more than 1,000 square miles. Nine of a total of 14 cooling units tested in the Timber Mountain caldera area have reversed polarity. As some of these units appear nearly identical and have discontinuous outcrops, their polarity, which is easily and quickly measured in the field, is commonly a unique identifying criterion. This criterion is also useful for identifying rhyolitic lava flows. One sequence of flows in particular produced intense negative aeromagnetic anomalies which appear to be useful for locating the flows in the subsurface of Pahute Mesa. Such data are extremely important for selecting sites for exploratory drill holes.

Studies of aquifer response to underground nuclear explosions

W. E. Hale, I. J. Winograd, and M. S. Garber have analyzed the changes in water levels in wells in the vicinity of underground nuclear explosions. Rises in water level of 10 to more than 400 feet have been observed in wells 8,000 and 2,000 feet, respectively, from an underground explosion of intermediate yield detonated within the zone of saturation. Rises as great as 1 foot have been detected at distances of 3 miles from another explosion of smaller yield detonated within the zone of aeration.

The observed rises in water level began within a few seconds to a few minutes following the detonation and reached a peak within several hours to several days. The water level then declined over a period of months before approaching the preshot water level. The tentative conclusion as to the principal cause for the rise in water levels is a slight net compaction of the aquifer skeleton in the vicinity of the shot, with attendant increase in water pressure. This response results in a water-pressure mound or ringlike water-table mound, surrounding the shot, that decays slowly to the original piezometric surface. Within the rubble chimney or collapse cylinder over the shot in the zone of saturation, the water level dropped markedly, and the depression may persist as a hydrologic sink for a number of years. The alteration of the flow system in the vicinity of shots made in the zone of saturation will have some effect on the distribution and transport of radionuclides in the vicinity of the shot.

PLOWSHARE PROGRAM

The aim of the PLOWSHARE Program of the Atomic Energy Commission is to develop peaceful uses of nuclear explosions. The Geological Survey participates in and contributes to this effort in various ways, including selection of sites potentially useful for experiments, making detailed studies of the geology and hydrology of explosion sites, and making feasibility studies of methods of beneficial water-resources development by use of nuclear explosions.

Site selection

The Geological Survey contributed to an investigation of possible sites for Project SCHOONER, a proposed nuclear cratering experiment in igneous rock. The purpose of the future experiment is to determine the cratering effects of nuclear explosions in a hard competent igneous rock and to compare the effects with those of the SEDAN nuclear cratering explosion in alluvium at the Nevada Test Site. Geologic mapping, seismic exploration, and drilling were done at several sites; final selection of a site for Project SCHOONER has not been made.

The Geological Survey also contributed to an investigation of possible sites for Project DOGSLED, a proposed nuclear cratering experiment in sandstone. This experiment is comparable to the proposed SCHOONER experiment and the accomplished SEDAN explosion.

Project GNOME

Project GNOME involved the detonation of a 3-kiloton nuclear device on December 10, 1961, in a salt bed near Carlsbad, N. Mex.

D. D. Dickey (1–64) has shown by preshot and postshot in-place acoustical measurements in the salt surrounding the point of explosion that the acoustic velocity of the salt decreased, owing to fracturing of the rock, for a radial distance of about 200 feet from the shot point.

Breakthrough curves were measured for tritiated water, iodine-131, strontium-90, cesium-137 and fluorescein during tracer studies in the Culebra dolomite aquifer at the GNOME site. Preliminary data analysis has shown promise in the use of field tracer experiments in predicting movement of certain ions in relation to water movement. In connection with determination of tracer concentrations of tritiated water in saline waters, R. W. Vernon and W. A. Beetem have shown that low concentrations of surface-active agents prevent coprecipitation interference in the liquid scintillation-counting procedure without the necessity of sample distillation.

Transport of radionuclides in ground water

F. W. Stead (1–63) has evaluated the available data on the distribution and transport in ground water of radionuclides from large underground nuclear explosions. The initial explosion-produced distribution of the biologically significant radionuclides around an underground nuclear explosion will be at, or a few orders of magnitude greater than, the maximum permissible concentration for these nuclides in drinking water, after the nuclides reach equilibrium between the rock matrix and the associated ground water. After restoration of the ground-water flow pattern to preexplosion conditions, the radionuclides will be transported by ground water down the regional hydraulic gradient and away from their initial explosion-produced area of occurrence. With a reasonable amount of data on the geologic and hydrologic setting of the area within which a nuclear explosion is to be detonated, the average rates and concentrations of radionuclide transport by ground water can be calculated, with validity within one or two orders of magnitude.

Strontium-90, a radionuclide characterizing the long-lived fission products, is significantly retarded in ground-water transport in virtually all geologic environments; its rate of movement will rarely be more than a few percent of the average velocity of ground-water flow, and in many environments will be a small fraction of a percent. Cobalt-60, a nuclide characterizing long-lived induced activities, also is significantly retarded in ground-water transport, more so than strontium-90. Tritium, a residual nuclide from fusion reactions, is not significantly retarded in ground-water transport; tritium may well prove the most important of all the long-lived nuclides in evaluating possibly hazardous radionuclide concentrations in ground water.

Project CHARIOT

Project CHARIOT is a proposed nuclear cratering experiment in northwestern Alaska to create an artificial harbor; the project has been deferred pending other cratering experiments being undertaken at other sites.

Results of laboratory studies made in 1961 on adsorption equilibria between samples from the CHARIOT site and biologically significant radionuclides were reported by J. H. Baker, W. A. Beetem, and J. S. Wahlberg (1–64). Strontium-90 adsorption from solution was found to be independent of sodium-ion concentration but decreased with increasing concentrations of the calcium and magnesium in the solutions. Strontium-90 adsorption from the solution by the solids tested was found to be relatively complete after only 1 day. Cesium-137 adsorption was also found to decrease with increasing total calcium-magnesium concentrations in the solutions. Distribution coefficients increased markedly with time in the case of cesium. This may be due in part to "fixation" reactions. Adsorption of iodine-131 was shown to increase with corresponding increases in the organic content of the adsorbing solids. In all cases, the dissolved radionuclides tested showed rapid uptake by the contacting earth materials.

Field studies were made by W. A. Beetem, V. J. Janzer, and Reuben Kachadoorian at the CHARIOT site in 1962 to obtain information regarding the removal and transport by water of the radionuclides iodine-131, cesium-137, and strontium-90. Test plots were chosen to represent a variety of micro-drainage patterns, vegetative cover, and soil types. Tracer isotopes were mixed with dry sifted soil of the same type as found in the vicinity of the test plot and then were applied uniformly to the plot. Water then was applied as a spray to simulate rain. Analysis of runoff water and soil samples indicate that very little radioactivity was transported in dissolved form from any of the test plots, regardless of the type of cover on the plots chosen. The character of the potential fallout evidently governs the movement of the radioactivity; with no movement of particulate material, there should be no transport of radioactivity.

VELA UNIFORM PROGRAM

The VELA UNIFORM Program of the Advanced Research Projects Agency of the U.S. Department of Defense is concerned with research on methods of detecting underground nuclear explosions. The Geological Survey, through the Atomic Energy Commission, provides information on the geologic and hydrologic environment of sites for nuclear explosions in this program.

Project DRIBBLE

Project DRIBBLE is a proposed series of nuclear explosions in salt at Tatum dome, Lamar County, Miss., to test the effect of decoupling on the detectability of underground nuclear explosions.

Basic hydrologic studies, completed during the current year, relating to the ground-water-contamination potential at the site involved primarily the hydrologic relation of the limestone caprock of the dome to the overlying and surrounding sand and limestone aquifers. Measurements of water level in the various aquifers indicate that the head in the limestone caprock is higher than in the overlying sand aquifers and lower than the head in the sand and limestone aquifers at depth along the flank of the salt dome. Pumping tests in a limestone caprock indicated a hydraulic connection with the overlying sand aquifers but no evidence of connection with the deeper aquifer. Nevertheless, the higher head of water in the limestone caprock suggests the possibility of some movement of water from the deeper aquifers through conduits along the flank of the dome and thence into the overlying and adjacent sand aquifers.

To aid in the interpretation of the seismic energy that will be propagated from explosions in Tatum dome, D. H. Eargle (1–64) has completed a study of the stratigraphic section of southeastern Mississippi.

DISPOSAL OF RADIOACTIVE WASTES

MOVEMENT OF RADIOACTIVITY IN STREAMS

Two major stream systems into which large quantities of radioactive waste are discharged have been intensively investigated by the Geological Survey in studies of radioactive-waste disposal.

Columbia River

The movement and deposition of radioactivity in the Columbia River below the Hanford, Wash., facility of the Atomic Energy Commission have been studied by W. L. Haushild, H. H. Stevens, Jr., and G. R. Dempster, Jr., in close cooperation with scientific personnel of the General Electric Co. They have found that the low-level radioactivity is mostly in solute form or is sorbed on suspended sediments of the river. Smaller amounts of radioactivity become associated with the biota. Significant quantities of scandium-46, chromium-51, zinc-65, zirconium-95—niobium-95, ruthenium-103—rhenium-103, and cerium-141, have been found. Ratios between the radioactivity in solution and that sorbed by the sediments vary considerably with time and place; they are not linearly related to the total amount of radioactivity, nor are the concentrations constant along a river cross section.

All bed sediments sorb some radioactivity, but relatively larger amounts are sorbed by sediments that contain larger amounts of silt- and clay-sized particles. However, large amounts of radionuclides are sorbed by bed sediments that contain less than 1 percent by weight of silt and clay. Chromium-51 and zinc-65 are most commonly sorbed by the bed sediments, but scandium-46, magnesium-54, and cobalt-60 are also found in close association with the bed sediments.

Tennessee River system

In a comprehensive study of the Clinch-Tennessee River system below Oak Ridge National Laboratory (ORNL), Geological Survey scientists in cooperation with those of the Health Physics Division, ORNL, and other federal and State agencies have studied the distribution of radioactive materials carried in solution and deposited in stream sediments over a distance of nearly 600 river miles.

The work has included an investigation of the hydraulic effects of the new Melton Hill Dam upstream from Oak Ridge. B. J. Frederick and P. H. Carrigan, Jr., of the Geological Survey and F. L. Parker of ORNL have found that hydroelectric peaking operations at Melton Hill Dam will lead to pulsed releases of waters from White Oak Creek, which drains the laboratory area, into the Clinch River. The largest pulse is released during the weekend shutdown of a typical sequence of summertime operations at the dam. Labeling the pulses with fluorescein dye has enabled the investigators to trace the water masses through a 16-mile reach. Maximum concentrations of the dye are reduced by a factor of 50 in the first 6.4 miles of the reach; a further twofold reduction occurs in the next 9 miles of the reach. In predicting diffusion in this unsteady flow system, the problem has been approached as an analog to flow in a tidal estuary.

The distribution of bottom sediments and the radioactivity associated with them have been studied by USGS–ORNL teams. P. H. Carrigan, Jr., and R. J. Pickering have found that in the first 8 miles downstream from the mouth of White Oak Creek, the lower water level of Watts Bar Reservoir and high discharges in the winter season lead to scour of sediments deposited in the summer. The beginning of thermal stratification from late spring to early fall centers about a section between 8 and 11 miles downstream. Stratified conditions do not seem to lead to any significant seasonal change in the longitudinal distribution of radioactivity in the bottom sediments in the vicinity of this section or farther downstream.

Variations in gross gamma radioactivity with depth in undisturbed cores of bottom sediment from the Clinch River have been measured in a "core scanner." Several of the longer cores show a repetitive general pattern of radioactivity which is very similar to the pattern of annual releases of cesium-137 from Oak Ridge National Laboratory since 1943. Most of the cesium-137 was associated with suspended sediment when it entered the river, and the observed repetitive pattern of radioactivity is considered by R. J. Pickering to be evidence that there has been continuous sedimentation at the locations from which the cores were taken. The persistence of the pattern in some cores whose length indicates an average yearly accumulation of only a fraction of an inch, in spite of known rather wide weekly variations in amounts of cesium-137 released to the river, testifies to the stability of the sorption reaction by which the radionuclide became fixed on the sediment particles.

The longitudinal distribution of cesium-137, cobalt-60, and trivalent rare-earth elements in the bottom sediments appears to be controlled by the same mechanism in the reach from Melton Hill Dam on the Clinch River to Kentucky Dam on the Tennessee River. The observed downstream decreases in concentrations are much greater than would be predicted on the basis of flow dilution alone. This suggests to P. H. Carrigan, Jr., that the mechanism is a sedimentation process. Somewhat different mechanisms may control the distribution of zirconium-95, niobium-95, and strontium-90.

In studies of the transport of radionuclides by White Oak Creek, W. M. McMaster has shown that the radioactivity load is more variable during base flow than at high discharges. Dye tracer tests in a 6,000-foot reach of White Oak Creek have shown that for flows ranging from 4.5 cubic feet per second to 200 cfs, peak concentration of the dye slug was nearly three times greater for flood flow than that during base flow, even though the quantity of dye and other conditions of the experiment were the same.

Studies of radioactive transport

Laboratory flume and theoretical analyses of the hydraulic problems of sediment dispersion and transport, fundamental to a knowledge of the processes controlling the movement of low-level radioactive wastes in streams, have been made by W. W. Sayre, D. W. Hubbell, and F. M. Chang.

The transport and dispersion of bed-material particles in alluvial streams have been described by Sayre and Hubbell in terms of a mathematical model in which the transport of a particle is represented as an alternating sequence of steps and rest periods of variable length and duration. In the language of stochastic processes, the model would be called a compound Poisson process with exponentially distributed increments. Using the initial condition of an instantaneous plane source of contaminated particles, uniformly distributed in the bed at a cross section, they arrived at a concentration-distribution function which agrees with observed distributions of radioactive-tracer particle concentrations along the North Loup River, Nebr., and in a laboratory flume, obtained at various dispersion times.

A method was also devised for determining the probability density function for the duration of rest periods of bed-material particles in an alluvial channel with bed forms. The only data required are continuous records of bed elevation obtained at a point.

Investigations of the dispersion of fluorescent dyes and suspended silt-size particles in a wide laboratory flume with a rough bottom using fluorometric and nephelometric tracing techniques have been initiated by Sayre, Hubbell, and Chang. Results to date indicate that the longitudinal dispersion of the dye from an instantaneous plane source follows closely the prediction of the Taylor-Elder theory of dispersion in a turbulent shear flow. In the theory a virtual coefficient of longitudinal dispersion is calculated from the velocity distribution and the Reynolds analogy for the equivalence of mass and momentum transfer. The suspended silt particles behave in a similar manner except that the tendency of the particles to settle is superimposed on the dispersion process. The rates of lateral dispersion of dye from a continuous point source within the flow and of floating polyethylene particles from an intermittent point source at the water surface were found to be virtually the same. The magnitude of the longitudinal diffusion coefficient was observed to be approximately 30 times that of the lateral diffusion coefficient. Measurements of the vertical distribution of dye from a continuous point source at mid-depth indicate that complete vertical mixing is obtained at a distance of about 15 times the depth downstream from the source. The results of both the longitudinal and the lateral dispersion experiments fit within the framework of the Fickian diffusion analogy.

DISPOSAL OF WASTES TO THE GROUND

At the Atomic Energy Commission's Savannah River Plant in South Carolina, I. W. Marine has used hydraulic data from pumping tests to estimate the degree of continuity of fracture systems between wells in crystalline bedrock, and has classified fractures in the bedrock according to their effect on gross rock permeability. Because of minute, very slightly permeable, interconnected fractures the rock mass can be considered as a single hydrologic system, but another system of fractures that are far more permeable transmit most of the water yielded by the test wells. Values for the coefficient of permeability derived from pumping tests range from less than 0.002 gallon per day per square foot for sound rock to about 1 gpd per sq ft for fracture zones.

The common practice in disposal of low-level wastes to the ground is to discharge them near the land surface into pits or cribs. Under these circumstances, a detailed knowledge of the occurrence of ground water and the geologic framework through which it flows and of the geochemical relations between waste, ground water, and the associated rock and soil materials are essential to an accurate prediction of the movement of wastes and the changes in concentration during transport.

R. M. Richardson (1–63) emphasized that sites for the disposal of release of radioactive wastes in arid regions are in general greatly superior to those in humid regions. In an arid climate, the great depth to ground water provides an unsaturated porous reservoir in which wastes are held temporarily while they decay; stream spacing is greater, thus requiring long travel times to points of discharge into streams; soils are more saline favoring ion-exchange reactions; and roots of vegetation do not commonly extend to the water table, thus eliminating a mechanism for recyling radionuclides that operates in humid regions.

A film illustrating the dispersion of aqueous radioactive waste in a heterogeneous aquifer, prepared from time-lapse photographs of dye in a series of hydraulic models, was presented by P. H. Jones and H. E. Skibitzke. This study showed that flow path, dispersion, and attenuation of radionuclide concentration were prominently influenced by aquifer geometry and permeability distribution.

In a general study of the hydrologic problems of injecting liquid wastes into deeply buried sedimentary rocks, W. J. Drescher (2–63) points out that precise definition of the flow, or even the forces affecting flow, cannot be quantitatively calculated for any one location on the basis of data available.

SITES FOR NUCLEAR POWERPLANTS

Julius Schlocker and others, in a detailed study of the site of a proposed nuclear steam powerplant at Bodega Bay, Sonoma County, Calif., made on behalf of the Atomic Energy Commission, found faults cutting Pleistocene sediments which rest on intensely faulted and fractured granitic bedrock at the site. The site is about 1,000 feet west of the edge of the San Andreas fault zone.

Sites at San Onofre, Calif., Haddam Neck, Conn., Malibu Beach, Calif., and Oyster Creek, N.J., have also been evaluated as to geologic and hydrologic suitability.

WATER CONTAMINATION STUDIES

The continued growth of population and industry is resulting in an increase in waste products in the geologic and hydrologic environments. A great variety of waste products tends to spread into ground-water and surface-water supplies in many instances restricting the use of an accessible supply, and in general complicating the development of water resources. In addition to pollution or contamination by waste products, some of our usable water resources are shrinking or are endangered at places where the pumping of wells (or some other action by man) alters a fresh-water—salt-water contact and causes salt-water movement. Investigations concerned mainly with contamination are mentioned in this section; investigations in which the described contamination is incidental to other matters are reported in the section "Water Resources," under Louisiana, South Dakota, Nebraska, Utah, Pacific Northwest, and California.

Environmental classification for disposal of wastes

Aspects of the hydrogeologic environment pertinent to ground-water contamination are being synthesized by H. E. LeGrand. He has developed a system for evaluating the contamination potential of sites where wastes are disposed of near the ground surface. His system uses the following interrelated factors: permeability, sorption, hydraulic gradient, depth to the water table, and distance from sources of contamination to a well supply.

DETERGENTS AND PESTICIDES IN WATER SUPPLIES

Laboratory studies

C. H. Wayman and colleagues have been studying the influence of physicochemical and biochemical properties on the movement of detergent solutions through both saturated and unsaturated ground-water zones. Their biodegradation studies show that under aerobic conditions, the newer type of "soft" ABS (alkylbenzenesulfonate) cannot be degraded in less than 1 week; under anaerobic conditions, satisfactory breakdown is not achieved even after 2 weeks. One of the nonionic surfactants, sucrose ester (a combination of sugar and natural oil), achieves nearly complete breakdown in about 1 day under both aerobic and anaerobic conditions. This is a significant finding that deserves careful consideration in the development of legislation regarding the production, use, and disposal of detergents in waste water.

Laboratory studies have disclosed also that two organisms, closely resembling *Flavobacterium peregrinum* and *Achromobacter*, could grow successfully on the fungicide DODINE (n-dodecylguanidine acetate), utilizing it as a sole source of carbon. This suggestion, that certain soil organisms can utilize specific fungicides as a carbon source, may further suggest that some soil sprays may become biodegraded before entering water supplies.

Detergents in Long Island ground water

N. M. Perlmutter, Maxim Lieber, and H. L. Frauenthal (p. C170–C175) report that water in the upper 20 feet of the water-table aquifer in the South Farmingdale area of Nassau County, N.Y., is contaminated by ABS (alkylbenzenesulfonate) in concentrations generally between 1 and 5 parts per million, but locally as high as 32 ppm. Most of the water in the remainder of the aquifer contains less than 1 ppm and does not foam. The source of contamination is effluent from hundreds of randomly distributed cesspools.

Detergent in the Martinsburg Shale in Pennsylvania

A ground-water investigation by L. D. Carswell and J. R. Hollowell in Dauphin County, Pa., indicates that water in the Martinsburg Shale is locally contaminated in the upper few feet of the saturated zone. Analyses of water samples from 44 wells showed low concentrations of ABS (alkylbenzenesulfonate) in most samples; only a few had concentrations exceeding 0.4 parts per million. The ABS in well waters is due to leakage around old, defective, and shallow well casings; leakage around uncemented casings and well seals; and widespread contamination of the limestone aquifers of the Martinsburg Shale.

Pesticides in Michigan water

A study of pesticide contamination in ground and surface waters of Van Buren County, Mich., by G. E. Hendrickson showed small but detectable contamination of some water sources by chlorinated hydrocarbons and organophosphates. Estimated concentrations of chlorinated hydrocarbons ranged from a few tenths to 5 parts per billion. Concentrations of organophosphates were estimated at 0.1 part per billion or less. Seven out of nine samples were lacking in one or both types of pesticides.

ACID MINE WATERS

Acid waters and sediment of the West Fork River basin, West Virginia

A reconnaissance of the water quality of streams tributary to the West Fork River between Weston and Clarksburg, W. Va., by G. W. Whetstone and C. R. Collier, showed that most of the tributaries are affected by acid mine-water inflow. However, only Lost Creek and Browns Creek are sufficiently contaminated to be classed as acid waters. Drainage from active and abandoned coal mines in the Browns Creek basin contains as much as 1,100 parts per million of H_2SO_4. Throughout most of its length, except in its extreme upper reaches, Browns Creek is acid (pH less than 4.5) and contributes about 6 tons of acid per day to the West Fork River. Approximately 1 ton of acid per day is from active mines; the rest is contributed by drainage from abandoned drift and strip mines. Sediment concentrations as high as 13,200 ppm during runoff from the thunderstorm were measured in one tributary draining a strip mine. The sediment concentration of Browns Creek is expected to range from 1,000 to 5,000 ppm during most storm-runoff periods.

High weathering rates in parts of the Monongahela River basin, Pennsylvania–West Virginia

Chemical weathering rates vary widely in the Monongahela River basin, Pennsylvania-West Virginia, because of lithologic and cultural influences. Measurements made during base flow in September 1963 by J. W. Wark showed natural removal of mineral matter in solution ranging from 0.003 to 0.07 tons per day per square mile, whereas calculated rates for streams receiving acid mine drainage were in excess of 1.0 ton per day per square mile.

Dissolved load in the Cane Branch basin, Kentucky

According to J. J. Musser, chemical weathering and erosion reached peak levels in 1959 in the Cane Branch basin, McCreary County, Ky. Acid drainage resulted from the weathering of pyrite exposed by coal strip mining in 1956 and 1959; since 1959, however, the concentration of dissolved solids in Cane Branch has slowly declined. The average dissolved-solids content for the low-flow months of 1959, 1960, and 1961 was 449, 367, and 336 parts per million, respectively, and for the high-flow months of 1959–60 and 1960–61, it was 213 and 148 ppm. Even though declining, these concentrations greatly exceeded those of nearby streams not affecting by mining.

Excessive manganese in the Muskingum River, Ohio

An increase in the manganese content of the Muskingum River between Zanesville and Beverly, Ohio, was observed by P. G. Drake during the low flow in the summer and fall of 1963. Surveys of the Muskingum River and selected tributaries made in July and October 1963 indicated that the manganese content of the river water averaged about 2 parts per million during the summer, approximately 3 times the normal concentrations observed in previous years. Moxahela Creek and Brush Creek, two tributaries which drain coal-mining areas, contained 4.8 and 13 ppm of manganese, respectively, in July and 18 ppm and 29 ppm in October.

INDUSTRIAL WASTES

Gasoline in ground water at Savannah, Ga.

A subsurface accumulation of refined gasoline described by M. J. McCollum (1–63) in downtown Savannah, Ga., floats on the water table adjacent to a building which houses stream-turbine generators of the Savannah Electric and Power Co. Fumes from the gasoline entered the sub-basement of the power-company building, creating a serious hazard. Auger holes were drilled to outline the gasoline body and to find the source of the gasoline. Apparently about 50,000 gallons of gasoline is present, lying from about 8 to 15 feet below land surface, depending on the local topography. To prevent fumes from entering the power-company basement, well points were installed to lower the water table and "gasoline table" and, at the same time, to concentrate the gasoline in the resulting cone of depression. A pumping system was installed and is presently removing the gasoline.

Waste load of the Passaic River, N.J.

Measurements of streamflow and dissolved-solids content at about 60 sites at low flow during September 1963, were used by P. W. Anderson and E. G. Miller to determine relative densities of dissolved solids on all significant tributaries and at several points on the main stem of the Passaic River, N.J. Preliminary information at Little Falls, N.J., indicates that the average dissolved-solids load per unit volume of water has increased consistently, while the average dissolved-oxygen content has decreased by about 20 percent during the past 20 years.

OIL-FIELD BRINES

Brine in water supplies near Alabama oil fields

Study by W. J. Powell, L. E. Carroon, and J. R. Avrett (1–63) of the Pollard, Gilbertown, Citronelle, and South Carlton oil fields in Alabama has revealed two major sources of contamination of fresh-water supplies: (1) brine-disposal pits underlain by permeable sands, and (2) leaking pipelines and wellheads that allow brines to percolate downward to the ground-water reservoir.

Source of saline water at Brunswick, Ga.

In a small area of salt-water-contamination in the city of Brunswick, Ga., the chloride content of water has remained at about 800 parts per million according to R. L. Wait. Increases in the chloride content of water from wells near the north (downgradient) side of the contaminated area indicate northward movement of water of high chloride content. Test drilling in the contaminated area showed that a dolomitic bed found above the salty water zone is very porous and is not an effective confining bed near the focus of chloride contamination.

Brine contamination of the Green River, Ky.

Continued study by R. A. Krieger of the oil-field brine discharge into the upper Green River in Kentucky shows that during the extremely low streamflows of 1963 about one-third of the brine was derived from the Metcalf County oil field and about two-thirds from the Greensburg field. However, total brine discharge to the Green River continues to decline. During the 1963 water year, the Green River at Munfordville was always well below the acceptable maximum of 250 parts per million chloride of the U.S. Public Health Service drinking-water standards.

SALT-WATER CONTAMINATION

Controls on brine discharge in Permian basin

Preliminary results of an investigation obtained under the direction of P. R. Stevens on the occurrence and movement of brine at many places in the Permian basin of Texas and adjacent States suggest that controls on brine discharge are regional, not local, and hence that efforts at control based on the assumption that the brines are generated by local circulation of infiltrated rain water are likely to fail.

Salt inflow to the Pecos River cut by pumping

About 420 tons of dissolved minerals, of which about 370 tons is sodium chloride, is added daily to the Pecos River through seeps and springs along a 3-mile reach of the river at Malaga Bend in southern Eddy County, N. Mex. The discharge of about 0.4 cubic foot per second (200 gallons per minute) of concentrated brine is from an artesian aquifer, at a depth of about 200 feet, near the base of the Rustler Formation. Studies by E. R. Cox indicated that the discharge of the brine to the river could be reduced substantially by pumping a well that taps the brine aquifer and by discharging the brine into a natural depression nearby. Pumping of about 550 gallons per minute of brine from July 22, 1963, to November 22 resulted in a reduction in head of about 8 feet in the brine aquifer. The head in the brine aquifer had been about 10 feet above river level before pumping began. Spot discharge measurements and chemical analyses indicate that the amount of salt entering the river at Malaga Bend had decreased about 50 percent by September 6, and about 60 percent by November 22. By December 27, about 328 acre-feet of brine containing more than 120,000 tons of salt had been pumped into the nearby depression. Leakage of brine from the depression has been less than 10 percent and may possibly be as low as 1 percent.

Saline ground water of the Outer Banks, N.C.

The movement of the salty ground water introduced into the sandy aquifers of the Outer Banks of North Carolina by the Ash Wednesday storm of March 7, 1962, was studied by H. B. Wilder. The initial slug of ocean water, which covered most areas less than 10 feet above mean sea level, moved rapidly down to the water table (2 to 10 feet) and by March 12 had contaminated wells less than about 15 feet deep. Along the beach, water having unusually high concentrations of chloride continued to move downward through the zone of saturation at rates usually ranging from 0.8 to 1.4 feet per day. Downward movement was slower farther inland.

Once the salty water reached the water table, the most significant movement appears to have been lateral. Maximum chloride concentrations did not exceed 5,000 parts per million in most wells, indicating that most of the recharging sea water did not permeate the zone of saturation. The pattern of chloride variation in individual wells was more erratic than would have resulted from a primarily downward mode of movement. Some shallow wells (less than 15 feet deep) did not show any effects of the salty water for more than 30 days after the storm, by which time the maximum contamination had already occurred in comparable wells known to have been inundated. Once the hydraulic energy of the storm-introduced water had dissipated, additional movement was very slow. One inland well, 60 feet deep, which was covered by sea water for several hours, did not show salt contamination for about 18 months. Other shallower wells which had yielded fresh water a few weeks after the storm, following an initial contamination, became salty again when subjected to heavy pumping during the summers of 1962 and 1963.

Saline ground water moving toward Baton Rouge, La.

Salt-water movement has been detected in the major aquifers of the Baton Rouge area, and appears to be moving northward toward centers of public-supply and industrial ground-water pumping according to C. O. Morgan and M. D. Winner (1–64). The decline of water levels around these centers has caused a reversal of natural hydraulic gradients, inducing movement of salt water toward areas of lower head. Preliminary estimates based on meager data indicate that salt water may be detectible at the nearest pumping center in 5 years at the present rate of pumping.

Salt water flow up Pascagoula River, Miss.

The severe drought of 1963 in southeastern Mississippi resulted in the lowest flow recorded in the Pascagoula River since 1936. Salt water from Mississippi Sound penetrated up the tidal reach of the river a record disance of 20 miles, 2 miles above any previously recorded penetration, according to H. G. Golden and

S. F. Kapustka. During a period of high tides and extremely low flows in October, salty water, for the first time known, reached above the division point of the main stem of the Pascagoula River.

Programmed disposal of salt from Project DRIBBLE

R. G. Lipscomb identified streambank vegetation along Half Moon and Lower Little Creeks, Lamar County, Miss., and established limits of chloride concentration that can be tolerated for specific periods of time. The studies were made in connection with proposed disposal of brine associated with mining of 40,000 tons of salt from Tatum dome in conjunction with Project DRIBBLE. See "VELA UNIFORM Program." It was concluded that the bank vegetation can tolerate water having a concentration of more than 1,000 parts per million, and possibly as much as 3,000 parts per million, of chloride if controlled release of brine is made into the streams. Using the estimated steamflow, which exceeds 17 cubic feet per second about 95 percent of the time and 30 cfs about 50 percent of the time, it was found that 75 tons per day of salt can be disposed of as brine into Half Moon Creek without exceeding a concentration of 1,000 parts per million of chloride. When the flow exceeds 30 cfs, 135 tons per day can be disolved in the stream without exceeding 1,000 parts per million of chloride. Disposal of 40,000 tons of salt could be effected from Tatum dome within 17 months without exceeding the limit of 1,000 parts per million of chloride in the Lower Little Creek system.

DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH

Environmental studies are receiving increasing attention in the field of public health. The rocks on which we live, the soils in which our foods grow, and the water that we drink are highly significant factors in the human environment, and the U.S. Geological Survey is participating in investigations of how these factors affect health. The natural distribution of elements in this context is treated in the following section; artificial distribution of mineral matter as related to health is treated under sections "Water Contamination Studies" and "Disposal of Radioactive Wastes."

Fluoride in ground water in Pacific Northwest

In an appraisal of fluoride content of ground water in the Pacific Northwest, A. S. Van Denburgh reported on water from 152 sources containing more than 1.0 part per million of flouride. Of these sources, 89 are in Idaho, 40 in Oregon, and 23 in Washington. The largest amount of fluoride recorded for each State is 24, 12, and 2.8 ppm, respectively. Thirty-two spring and well waters in Idaho contained more than 10 ppm. The high-flouride ground water is chemically distinctive in that it is soft, has a high pH, and contains large amounts of silica. Most of the high-fluoride water is obtained from deep wells that commonly tap aquifers in volcanic rock.

Arsenic in ground water in Lane County, Oreg.

E. L. Goldblatt, A. S. Van Denburgh, and R. A. Marsland report above-average arsenic content of ground water in Lane County, Oreg. Water containing the greatest amount of arsenic is confined to the Fisher Formation. Arsenic in amounts exceeding the 0.05 parts per million (the limit according to U.S. Public Health Service drinking-water standards) is found largely in the ground water within a 100-square-mile area west and south of Eugene. Most of the ground water in Lane County contains little arsenic and does not constitute a health hazard, but water from wells in that part of the county in the Willamette Valley south of Eugene should be tested for arsenic content prior to intended domestic use. (See also "Geochemistry of Water".)

ENGINEERING GEOLOGY

Clay a hazard in part of the Washington, D.C., area

Clay of the Patapsco Formation of Late Cretaceous age presents a geologic hazard to construction in the eastern and southern parts of the Washington, D.C., metropolitan area, where it has been used extensively for making brick. Exposures of the clay on steep slopes are generally stable only so long as they are undisturbed. Moreover, the clays are subject to expansion and rebound when they are unloaded by removal of overburden, as was recognized by C. F. Withington (1–64) during a study of a slope failure in an excavation at Greenbelt, Md. Although the rebound is not great, it is enough to open incipient joints in the clay, and where they are parallel to the wall of a vertical cut, the cut stability is impaired.

Swelling clays discovered in Seattle freeway

Excavation for a freeway on Capitol Hill in Seattle, Wash., revealed previously unrecognized greenish weathered montmorillonitic clay. Studies by D. R. Mullineaux, T. C. Nichols, and R. A. Speirer (chapter D) indicate that the weathering occurred prior to the Vashon glaciation, before 15,000 years B.P. The distribution of the weathered clays is important in planning for heavy construction because they are characterized by higher swell pressures and lower shear strength than comparable unweathered clays in the Seattle area.

Swelling clays in Palo Alto, Calif.

Mapping by E. H. Pampeyan in the Palo Alto quadrangle has led to recognition of a zone of Eocene montmorillonite-rich clayey siltstone that passes through two residential developments. Homes and roads along the zone had been damaged by the swelling and contracting movements that accompany seasonal climatic changes. Free-swell tests for unconfined volume change on wetting show as much as 80 percent swell for some of the clayey beds as compared with 10 percent for adjacent sandstones. Plans for using as yet undeveloped land underlain by the swelling clays need to be carefully reevaluated.

Distribution of coal-mine bumps at Sunnyside, Utah

Continuous seismic recording of bumps in coal mines near Sunnyside, Utah, during the fall of 1963 revealed a cyclic occurrence of these events. According to F. W. Osterwald, the maxima occur at intervals of 5 to 9 days. The number of bumps recorded per day increased steadily during November but decreased during the first part of December, whereas the intensity of individual bumps increased. During December, several bumps occurred along a fault system that extends through the Sunnyside No. 2 and the Columbia mines. These bumps seemed to increase progressively in number and in intensity. An extremely violent bump occurred on December 24 in which two men were injured and much damage was done to the Sunnyside No. 2 mine. Preceding the violent bump, two moderately violent bumps associated with the fault system were recorded in the same area. The "epicenter" of this bump was only about 300 feet from a major fault intersection, whereas the center of physical damage was in a large coal pillar surrounded by small ones. The faults apparently provided convenient places for stress accumulation that was released violently by mining activity in the large pillar. As a result of this sequence of documented events, it may be possible in the future to predict areas in which stress is accumulating. Hence it might be possible to increase the safety of mining operations by avoiding certain dangerous areas during periods of intense bumping activity as recorded by seismographs on the surface and underground.

Recent surface movements in the Baldwin Hills, Los Angeles, Calif.

Surface movements in the north-central part of the Baldwin Hills have been observed and measured in recent years by several city and county organizations. Data available to the middle of 1962 were obtained as supplemental information during the U.S. Geological Survey investigation of the surface geology of the Baldwin Hills area by R. O. Castle [31] and have been correlated with the local geology and summarized (U.S. Geological Survey, 10–64). These data indicate that the movements consist predominantly of subsidence and cracking of the ground.

Contours of equal rate of subsidence form a pattern that is elongated somewhat along a northwest-southeast line roughly paralleling the axis of the Inglewood oil field structural dome. Cracking that developed in the period 1957–62 is along five north-northeast-trending ruptures in the vicinity of the intersection of La Brea Avenue, Stocker Street, and Overhill Drive. Offsets on the cracks ranged from less than an inch to about 5 inches and defined a trough several hundred feet wide and about 2,500 feet long. The surface cracks conform in direction to northeast-trending bedrock faults that offset the major north-northwest-trending Inglewood fault.

Possible causes of ground movements are (1) changes in reservoir pressure due to oil-field operations, (2) changes in ground-water conditions, (3) compaction of sedimentary materials, and (4) tectonic movements. Similar factors are being evaluated by several State and municipal boards of inquiry that are considering the failure of the Baldwin Hills Reservoir on December 14, 1963.

Landslide at portal of highway tunnel, Colorado

The use of an approach road under construction and the start of the estimated $50 million Straight Creek tunnel were threatened by development of a landslide in the cut at the east portal of the tunnel. C. S. Robinson, R. A. Carroll, and F. T. Lee (1–64), in cooperation with the U.S. Bureau of Public Roads and the Colorado Department of Highways, used geological and geophysical methods to define the extent of the landslide in fractured bedrock and surficial material and to predict its possible behavior. Resistivity surveys

[31] R. O. Castle, 1960, Geologic map of the Baldwin Hills area, California: U.S. Geol. Survey open-file report.

made by the Bureau of Public Roads and geologic and shallow seismic surveys made by the U.S. Geological Survey yielded complementary and generally concordant data that allowed a definition of the volume and mass of the landslide. These data were used by the Bureau of Public Roads to design methods of stabilizing the landslide so that construction of the tunnel could proceed.

Gravity surveys can detect caverns under reservoir

A precision gravity survey of areas of known leakage on the floor of Anchor Reservoir in Wyoming, made by G. P. Eaton at the request of the U.S. Bureau of Reclamation, indicated that areas of potential leakage associated with cavernous openings in bedrock beneath shallow alluvium can be detected readily by the gravity method. Negative anomalies ranging from −0.1 milligal to −1.0 mgal were found to be associated with areas of actual leakage and to show up clearly on a gravity map prepared from observations made on a station grid with spacing of 50 by 100 feet.

Uncertainties in the seismic determination of "top of rock"

In Southborough, Mass., a quartzite of normal lithology and structure, but with compressional-wave speed of 3,100 to 4,300 feet per second, led to misidentification of actual bedrock as till composing the second seismic layer. Geologic mapping by N. P. Cuppels, and additional field seismic measurements by C. R. Tuttle and R. N. Oldale show that the speed is unrelated to frequency and to instrument malfunction. The "seismic top of rock" boundary is commonly unrelated to the base of primary weathering, to the "shattered rock" boundary, to shear zones, or to the original ground surface. Two 180° fan arrays of geophones show that surface vector speeds measured directly on the quartzite are fastest normal to the strike of points; a third fan discloses fastest compressional speed both parallel and also at 60° to the strike of major joints and lithic contacts; these measurements contradict ray-path theory. Ray paths are evidently not guided by dip because the critical angle is an average of 20.7° normal to the strike, and 17.2° parallel to strike, whereas dip of geologic structure averages 50° in the vertical plane of seismic-transverse azimuth and ranges from 38° to 63°.

Relation of elasticity to strike of bedding

Elastic-parameter measurements were made at two seismic field model sites in Massachusetts by C. R. Tuttle, using nonexplosive energy sources and a cathode ray tube-type interval timer. At North Attleboro, measurements were made through 11.5 feet of till in underlying fine-grained arkosic conglomerate. Modulus of elasticity (E) normal to strike of the bedding, compared with E at about 45° to the strike, was in the ratio of 2.3 to 1.0. On the theoretical curve of Poissons ratio versus the ratio of compressional to shear speeds, the data normal to the strike lie on the curve, whereas a measurement at 45° to the strike of bedding lies far outside this curve. When supported by additional field measurements, this relation might be diagnostic of the direction of concealed geologic structure. Shear measurements at a site where bedrock was covered by about 12 feet of sand were unsuccessful, probably because of attenuation through a nonrigid material.

ENGINEERING HYDROLOGY

Hydrologic science is widely applied in engineering practice, but for the most part such applied work is done by private firms or public agencies involved directly in construction or management of projects. The work of the U.S. Geological Survey in this field is directed toward broad fundamental studies that are common to many areas and projects.

LAND SUBSIDENCE

Draft on confined ground-water reservoirs throughout the country is increasing, causing increased decline in artesian head and consequent increased effective stress on the confined aquifer systems. For this reason, subsidence of the land surface resulting from aquifer compaction can be expected to become more widespread and intense. Subsidence causes serious problems in the construction and maintenance of engineering structures, especially overland water-conveyance systems. In addition, the compaction of aquifer systems in subsiding areas has caused the destruction of hundreds of wells owing to compressive failure of the casings. In contrast to its destructive aspects, aquifer compaction supplies large quantities of water from storage in the fine-grained semipervious compressible interbeds or confining beds. Such water is, however, a nonrenewable resource, and the process of mining it changes the hydrologic properties of the system, especially the coefficient of storage.

Studies of land subsidence caused by decline in artesian head are continuing in California, Nevada, Arizona, and Texas. These studies are contributing to knowledge of the mechanical and hydraulic properties of leaky aquifer systems, the storage characteristics of semipervious interbeds and confining beds, the change in the coefficient of storage with time and change in effective stress, and the inability of most well casings to resist the compacting forces. A special case of land subsidence occurred during the earthquake in Alaska in March 1964, described under "Alaskan Earthquake." A special case of compaction due to nuclear explosion is described in the section "Investigations Related to Nuclear Energy."

Reduced land subsidence and compaction in California

B. E. Lofgren finds that a marked change in the rate and areal extent of subsidence occurred in the Tulare-Wasco area in the southeastern San Joaquin Valley during the years of 1962 and 1963 when surface-water supply was ample. Partial releveling of the bench-mark net by the U.S. Coast and Geodetic Survey in Febraury 1964 indicated that the rate of subsidence in much of the area was greatly reduced compared to the average rate from 1959 to 1962, a period of deficient surface-water supply. A direct relation exists in each part of the area between the rate of subsidence and the ground-water pumpage, which in turn is inversely related to the surface-water supply. Only in the vicinity of Pixley, where surface-water deliveries have been limited, did subsidence rates exceed 0.2 foot per year from 1962 to 1964. Total subsidence in the cone of subsidence near Pixley from 1930 to 1964 has been 11.5 feet.

Compaction recorders installed in central California

Highly senstitive compaction recorders have been installed at several sites in central California to measure the compaction of the aquifer system due to artesian-presure decline. Using a gear mechanism to expand the compaction record as much as 48 times, the sensitive response of the unconsolidated deposits to slight increases in effective overburden stress has been recorded. Within minutes of the time that water levels are drawn down by nearby pumping at a compaction recorder near Pixley in Tulare County, compaction of the producing aquifer system is recorded. Declines in artesian head of as little as 5 feet are sufficient to cause noticeable compaction of fine-grained deposits 500 to 700 feet below the land surface. The change in effective stress represented by the 5-foot decline is less than 1 percent.

Well casing shortened by compaction in California

In the southern part of the Los Banos–Kettleman City subsidence area, on the west side of the San Joaquin Valley, measurements have been made on the compression and shortening of a heavy oil-well casing encased in cement. J. F. Poland and R. L. Ireland have found that in the 20 months from August 1962 to April 1964, total measured compaction of sediments from land surface to a depth of 1,930 feet was 1.08 feet and concurrent shortening of the 11⅝-inch 54-lb (per foot) oil-well casing was 1.03 feet. In this period the top of the casing moved up 0.05 foot with reference to the land surface. These measurements indicate that the skin friction between the casing system (casing and cement) and the sediments is sufficient to overcome the compressive strength of the heavy casing and cement envelope when compaction of the sediments occurs. Therefore, in sediments undergoing compaction due to fluid withdrawal and increase in effective stress, such structures obviously cannot be utilized as reference bench marks for leveling control, even if they pass completely through the compacting sediments. Furthermore, the increase in protrusion of the casing top above land surface may represent only a negligible part of the land subsidence.

Rate of subsidence increasing in Las Vegas Valley, Nev.

According to G. T. Malmberg (1–64), analysis of a releveling of part of the Hoover Dam level network by the U.S. Coast and Geodetic Survey during May and July 1963 indicates that land subsidence since 1935, resulting principally from ground-water withdrawals in Las Vegas Valley, has affected an area of about 200 square miles and that maximum subsidence exceeds 2 feet. Subsidence has been most pronounced in Las Vegas and North Las Vegas, and since 1951 the rate of subsidence has been about 0.1 foot per year, or more than double the rate during 1935–51. The accelerated rate of subsidence since 1951 is the result of the increased overdraft on the ground-water reservoir and the consequent reduction in artesian head. Precise leveling by the Coast and Geodetic Survey in 1935, 1941, 1950, and 1963 indicates that the volume of subsidence resulting largely from the compaction of saturated valley-fill deposits during successive intervening periods was about 2,000, 12,000, and 28,000 acre-feet, respectively, or about 3 to 4 percent of the pumpage during those intervals.

Subsidence and earth cracks in southern Arizona

In southern Arizona, land-surface subsidence has been recognized in several valleys where water levels have been lowered substantially by pumping. Collapse of well casings below the water table is indicative of compaction of sediments and reservoir volume change due to vertical shortening. Increased protrusion of the top of a well casing above the land surface indicates subsidence but supplies only a minimum clue to the magnitude, because most of the compaction of sediments may be represented by casing shortening or failure at depth (as shown by the measurements reported near Westhaven in the San Joaquin Valley, Calif.). William Kam has measured the increased protrusion of well casings above the land surface at Luke Air Force Base, Maricopa County, Ariz. The rate of protrusion at two wells, 501 and 1,200 feet deep, is about 0.02 foot per month. At some places, well-casing collapse below the water table and the development of nearby earth fissures at land surface appear to be related to land subsidence as indicated by casing protrusion. There also seems to be a correlation at some places between the occurrence of earth fissures and facies boundaries in the subsurface deposits.

Compaction of aquifer measured at Houston, Tex.

Two compaction recorders are being operated in the Houston area. At a well 1,650 feet deep in a city of Houston well field, R. K. Gabrysch reports measured compaction from September 1959 to March 1964 was 0.15 foot. At a well 770 feet deep at the NASA Manned Spacecraft Center, Clear Lake, Harris County, measured compaction from October 1962 to March 1964 was 0.12 foot. The U.S. Coast and Geodetic Survey is now releveling the Houston area as part of a 5-year releveling program. However, results of this releveling are not yet available for comparison with measured compaction.

EVAPORATION SUPPRESSION

Efficiency of films proportional to length of carbon chain

Laboratory experiments to suppress evaporation by monomolecular films lead G. E. Koberg to conclude that the longer the carbon chain is in the film molecule, the more effective the film is in reducing evaporation. Mixtures of compounds of different chain lengths will not be as effective as a film composed only of the compound having the longest chain. The laboratory experiments also revealed that the films are more effective under an unstable atmospheric condition (when the temperature of the water surface is higher than that of the ambient air) than under a stable condition.

Bubbler method successful in field test

An investigation in collaboration with the Escondido Mutual Water Co. of a method of reducing evaporation by mixing the cold and warm water of Lake Wohlford, in southern California, indicated a saving of water through below-average evaporation of 14 percent for the period May through July 1962. For the period September through November 1962 a comparable loss through increased evaporation of 8 percent was noted by G. E. Koberg (chapter D). The increase in evaporation was attributed to the additional energy stored in Lake Wohlford during the May through July period because of the reduction in evaporation. During the 1963 year, similar evaporation results were obtained. Mixing of the water was accomplished by forcing 210 cubic feet per minute of free air into the water at a point 40 feet below the surface of the lake.

The bubbling of air in Lake Wohlford is now considered a routine operation by the water company because of the improvement of water quality and the net reduction in evaporation. One significant change was made in the operation schedule of the system during 1963 from that of 1962. The 1962 schedule required the system to operate 9 hours each day. However, circulation studies during the 1962 year indicated that for optimum operation, the system should be operated over an interval of at least 24 hours or longer to obtain complete circulation in the lake. The schedule for 1963 was changed to two operations a week of 30 hours duration each. Further studies are planned in southern California to determine if such systems are economically feasible on larger reservoirs.

FLOODS

Three major categories in the study of floods by the U.S. Geological Survey are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals. The following section, accordingly, is subdivided into outstanding floods of 1963–64, studies of flood frequency, and flood mapping.

OUTSTANDING FLOODS OF 1963–64

Flood of August 7, 1963, at Buffalo, N.Y.

More than 3 inches of rain in the metropolitan Buffalo area on July 29, 1963, was followed by 3.88 inches on August 7. The 24-hour rainfall on August 7 was the greatest since 1893 at Buffalo, and the resulting flood was the most damaging in the history of the city. Damage was estimated at $7 million to public property and $28 million to private property.

Flood of August 20, 1963, in Alexandria-Arlington, Va.

Severe flooding in the Alexandria-Arlington metropolitan area occurred on August 20, 1963, as a result of cloudburst rainfall of 3.4 to 3.9 inches in 1½ hours over most of the Fourmile Run drainage basin. The peak flow of 11,400 cubic feet per second at the gaging station on Fourmile Run at Alexandria was the greatest known and was estimated to have a recurrence interval of 100 years. One life was lost in the floodwaters of Long Branch along Army-Navy Drive in Arlington. Damage was estimated to be in excess of 1 million.

Floods of early August 1963 in Puerto Rico

M. A. Lopez reports damaging floods in southwestern Puerto Rico during the period July 30–August 3, 1963. On July 30, the highest flood since 1933 on the Rió Yagüez inundated homes, schools, stores, and industries close to the center of Mayagüez, Puerto Rico's third largest city. Flooding of 4,000 acres of reclaimed land in the Lajas valley project resulted from 9 inches of rain on August 2–3. Inundation lasted as long as 5 days, and damage to young sugarcane was considerable. The flood was the most sever since drainage works were started in 1955.

On August 3, the highest flood since 1954 occurred on the Rió Guayanilla. Moderate damage occurred to sugarcane lands and low-lying homes and business establishments in the small city of Guayanilla, and the main Highway 2 was inundated.

Floods of March 1963, Alabama to Ohio

H. H. Barnes, Jr. (1–63) reports that widespread disastrous floods struck the western slopes of the Appalachian Mountains from Alabama to Ohio as a result of three storms moving over the area during the period March 4–19, 1963. The initial storm, March 4–6, established conditions favorable for maximum runoff from subsequent storms. Heavy rainfall during March 11–13 produced record-breaking floods on many streams. The third storm, March 16–19, prolonged flooding and produced high-volume runoff in some areas.

Alabama.—Three people died as a result of the storms, and flood damage was estimated in excess of $1 million. The peak discharge at three gaging stations exceeded the maximum previously known, and had recurrence intervals ranging from 80 to more than 100 years.

Tennessee.—Records from 18 stream-gaging stations in the eastern part of the State reflect the maximum peak discharge since systematic data collection began. The March 13 peak discharge of 56,700 cubic feet per second on the Clinch River at Tazewell is second only to the flood of 1862. The March 12 peak discharge of 25,800 cfs on the Sequatchie River near Whitewell is the maximum known since at least 1867. The March 12 peak discharge of 35,000 cfs on the Elk River above Fayetteville equaled the flood of 1949, and the stage reached within half a foot of the record 1842 crest.

During the predawn hours of March 12, an unprecedented flood crest of 32,700 cfs from a drainage area of 97.5 square miles swept through the Little Sequatchie River valley above Alum Cove, claiming four lives and causing much destruction.

Statistics compiled by the Tennessee Division of Water Resources reveal: more than 3,000 homes damaged or destroyed, about 1,500 head of livestock lost, more than 100,000 acres of winter crops damaged, almost half a million acres of cropland damaged, and 1,000 bridges damaged or destroyed in 50 counties, with the total damage appraised in excess of $10 million.

Kentucky.—Flood peaks at many gaging stations in southeastern Kentucky approached the maximum for the period of record, and new maximums were established at five gaging stations. Extreme flooding occurred in the upper basins of the Big Sandy, the Cumberland, and the Kentucky Rivers. The range of peak discharge was between 60 and 200 cubic feet per second per square mile, and the recurrence interval was between 15 years and 1.9 times the 50-year flood. The Army Corps of Engineers and the U.S. Weather Bureau estimated the total damages in Kentucky to be about $50 million.

West Virginia.—The floods of March 12 in the Guyandotte and the Big Sandy River basins were the highest of record and the highest since at least 1915. As a result of more than 2 weeks of flooding in the western sector of the State, 5 lives were lost, about 5,000 persons were forced from their homes, and estimates of property damage amounted to more than $10 million.

Virginia.—In general, the floods of March 12 on streams in the Tennessee River basin in southwest Virginia were the second highest in 100 years, being exceeded only by the 1957 floods. The flood of March 13 on the Clinch River at Speers Ferry was the greatest since 1862. Floods at two gaging stations in the Big Sandy River ranged from 2 to 2½ times the 50-year discharge.

Ohio.—In the flood of March 1963 in central Ohio, peaks on some streams in the Hocking River and the Scioto River basins exceeded those for the disastrous flood of March 1913. Profiles of the Hocking River flood stages and an inundation map of Athens, Ohio, provide useful information for the design of highway bridges and culverts and other structures in the Hocking River valley.

Floods of March 1964 in the Ohio River valley

Two intense storms within a week during the first half of March 1964 caused outstanding floods on the Ohio River and many of its tributaries. The storms covered a wide band that generally parallels the Ohio River. Floods along the Ohio River were the highest since 1945 at some gaging stations, and flood records were broken at many points in Indiana, Ohio, and Kentucky. The peak discharge for many streams tributary to the Ohio River exceeded the discharge for the 50-year flood. Preliminary estimates of flood damages exceed $20 million. According to estimates by the Army Corps of Engineers, flood crests were reduced 2 to 10 feet and many millions of dollars were saved by the Engineers' flood-control works in the Ohio River basin.

Flood of July 16, 1963, at Hot Springs, Ark.

A thunderstorm on July 16, 1963, at Hot Springs, Ark., and vicinity produced floods on Gulpha Creek and tributaries, Hot Springs Creek, Glazypeau Creek, and many smaller streams. The peak discharge at some points was more than twice the magnitude of the 50-year flood discharge. In Hot Springs, the downtown was flooded in the worst flood since May 1923. Estimate of property damage in the city of Hot Springs was $1 million to private property and $150 thousand to streets, bridges, and sewerlines, and in the remainder of Garland County damage was estimated as $1 million to private property and $200 thousand to public property.

Floods of June 24–25, 1963, in Nebraska

Studies by E. W. Beckman indicate that peak runoff rates at least as high as 2,900 cubic feet per second per square mile from a 0.3 square-mile area and 1,800 cubic feet per second per square mile from a 40 square-mile area occurred June 24, 1963, around a storm center in east-central Nebraska. The recurrence interval for the peak discharge at many points exceeded 100 years. Data collected by the U.S. Weather Bureau, the Army Corps of Engineers, and others show a principal storm center in eastern Butler and western Saunders Counties. The highest storm-total rainfall measurement was 16.5 inches, of which a maximum of 3.8 inches fell in 1 hour. Four inches or more of rain fell over an area of 4,300 square miles.

Flood of September 17, 1963, in southeast Texas

Hurricane Cindy caused torrential rains approaching 24 inches in the Beaumont–Port Arthur area of the southeast corner of Texas on September 17, 1963. This is apparently the highest 24-hour rainfall in Texas since the storm of May–June 1935. Although flood damage was extensive, no lives were lost. Several streams in the area had peak discharges in excess of 50-year frequency, and one recorded peak was 1½ times the discharge for the 50-year flood.

Floods of August 1963 in Prescott, Ariz.

Several rainstorms during the early part of August set the stage for high runoff from an intense rain on August 19, 1963 (Aldridge, 1–63). At about 8 p.m. on Monday, August 19, 1963, four small tributaries of Granite Greek poured water into Prescott at a combined rate of over 7,000 cubic feet per scond, causing $400 thousand damage to real estate, streets, sewers, waterlines, and personal property. Houses were washed off their foundations; cars, trucks, and trailers were washed away; but miraculously no one was killed or injured. Higher floods may have occurred in the last 50 years, but none of them caused nearly as much damage.

Floods in southern Idaho during February 1963

C. A. Thomas reports that extreme flooding occurred in rather widely scattered tributaries of the Snake River in southern Idaho during the first 4 days of February 1963. Conditions that caused the flood were very similar to those that caused the extreme floods of February 1962; however, the area affected was smaller. Peaks on several streams exceeded those for the February 1962 flood. The recurrence intervals for some peaks ranged from 50 to more than 100 years.

Severe flood in Nevada, early February 1963

Widespread flooding occurred in northwestern Nevada during January 31–February 1, 1963, as a result of intense precipitation of about 72-hours duration, according to S. E. Rantz and E. E. Harris (4–63). The flood-producing storm was of the warm type; precipitation fell as rain at altitudes as high as 8,000 feet. The heavy precipitation, totaling as much as 20 inches or more in the Sierra Nevada, fell on frozen ground or on a sparse snowpack at higher altitudes. The response of runoff to rainfall was dramatic; streams throughout northwestern Nevada rose rapidly. Major flooding ocurred throughout the Walker, Carson, and particularly the Truckee, River basins, where flood peaks either reached record-breaking heights or rivalled the discharges attained in the memorable floods of November 1950 and December 1955. Because of the relatively short duration of the storm, the volume of flood flow in 1963 was not outstanding. The flood peak for the gaging station on the Truckee River at Reno, Nev., was only slightly less than the devastating flood of December 23, 1955; this was due in part to the newly constructed Prosser Creek Reservoir in the upper watershed.

Ice-jam flooding in Alaska

R. E. Marsh reports that Lake George, near Palmer, which usually forms behind Knik Glacier, did not break out in 1963. This is the first time that there was no breakout since at least 1948, when the U.S. Geological Survey began studies of the high-flow period, and probably since 1918, according to personnel of the Alaska Railroad.

The maximum stage of the Yukon River at Rampart (58.69 ft, from floodmarks) was much higher than any other stage for the period of record, and according to local residents, it was the highest stage ever reached from an ice jam.

Floods of March-May 1963 in Hawaii

Intense localized rains during March through May 1963 caused damaging floods in several areas of the Islands as reported by W. C. Vaudrey (1–63). Excessive rains occurred in the Koloa district, Kauai, on March 5–6; near Waimanalo, Oahu, on March 6; and near Hana, Maui, on March 13. In the latter area, rainfall intensity was 4 inches in 45 minutes. Heavy rains fell on all islands on April 14–15, the resulting flood damage being greatest on Kauai and windward Oahu. A driving storm hit suddenly May 14 and dropped nearly 6 inches of rain in 3 hours on leeward Oahu. One child was drowned in the flood from this storm.

At 22 gaging stations, peak discharges resulting from the series of March-May storms exceeded previous maximums. On April 15, the previous 45-year maximum discharge at Hanapepe River near Eleele, Kauai, was exceeded by 11,800 million gallons per day, and at South Fork Wailau River near Lihue, Kauai, the previous 48-year maximum discharge was exceeded by 18,400 mgd.

The March–May floods caused 4 deaths and property damage in excess of $2 million. The Army Corps of Engineers estimates that its flood-control works on the Hanapepe River prevented an additional $292 thousand damage.

FLOOD FREQUENCY

Effect of urbanization on floods at Jackson, Miss.

Preliminary analysis of 10 years of record on streams draining the city of Jackson reveals that some flood crests are increased appreciably by urbanization. K. V. Wilson and others have found that the increase ranges from 200 to 300 percent, depending upon the degree of development and the relative magnitude of the flood. The study reveals that the degree of effect decreases with increasing flood magnitude.

Discharge-frequency relations in Mississippi

Preliminary analysis of peak discharges from drainage areas of less than 2 square miles reveals that runoff rates increase as drainage areas decrease. According to recent studies by K. V. Wilson and colleagues, the discharge-frequency relations for small drainage areas do not conform to the relations previously established [32] for larger streams in Mississippi. Eight years of annual peaks at 25 gaging stations and outstanding floods at many miscellaneous sites were used in the analysis.

Rainfall-runoff relations in Mississippi and Louisiana

More than 900 floods above an arbitrarily chosen base have been analyzed to determine the rainfall-runoff relation for streams that drain southwestern Mississippi and southeastern (Florida parishes) Louisiana. A. J. Calandro and colleagues have determined that a family of curves will relate total rainfall to total runoff. Different curves are applicable for the several seasons of the year.

Magnitude and frequency of storm runoff in Mississippi and Louisiana

V. B. Sauer (chapter D), used records from 17 gaging stations ranging in drainage area from 0.73 to 1,330 square miles to define the relation between magnitude and frequency of storm runoff for individual storms within a 7,500-square-mile area in southwestern Mississippi and southeastern Louisiana. It was demonstrated that the recurrence interval for a given storm runoff is not necessarily the same as the recurrence interval for the peak discharge resulting from that same storm.

Flood-frequency relations of Alaska streams

According to V. K. Berwick, the magnitude-frequency relations of floods in Alaska south of the Yukon River can be determined with a reasonable degree of accuracy for most sites, gaged or ungaged, on streams that are unaffected by the works of man. Drainage area alone is used as the independent variable for correlation with the mean annual flood. Results are limited to sites above which the drainage area is within the range of that covered by the base data.

[32] K. V. Wilson, and I. L. Trotter, Jr., 1961, Floods in Mississippi, magnitude and frequency: Mississippi State Highway Dept.

Flood-frequency relations of Texas streams

The magnitude of a flood of any selected frequency between 1.2 and 50 years can be estimated for most natural-flow streams in Texas that drain areas of 40 square miles or more, according to a report by J. L. Patterson (1–63). The report contains tables of maximum floods at gaging stations and miscellaneous sites, and tabulations of floods above a selected base discharge for gaging stations having 5 years or more of record as of September 30, 1961.

Flood-frequency relations of Wyoming streams

A report by J. R. Carter and A. R. Green (1–63) describes methods for estimating the magnitude of a flood of any frequency between 1.1 and 50 years for any site, gaged or ungaged, on most unregulated streams in Wyoming, within the limits of basin size for which records have been collected. Flood-frequency relations are not defined for a large part of the headwaters of the North Platte River in south-central Wyoming because of the scarcity of streamflow data.

Nationwide flood-frequency reports

Nine reports have been completed in the nationwide series of 19 reports on the magnitude and frequency of floods, and 6 will soon be submitted by authors for approval. Each report is for a part corresponding to a drainage-basin subdivision used by the Geological Survey. The following reports have been published: Part 3–B, Water Supply Paper 1676 (Speer and Gamble; 2–64); Part 7, WSP 1681 (Patterson, 1–64); Part 13, WSP 1688 (C.A. Thomas, Broom, and Cummans, 1–63); Part 14, WSP 1689 (Hulsing and Kallio, 1–64), WSP 1673 (Speer and Gamble, 1–64); and Part 12, WSP 1687 (Bodhaine and Thomas, 2–64).

FLOOD MAPPING

Flood maps of urban areas

Flood-inundation maps showing the limits of inundation by major floods, flood profiles, stage-frequency relations, and descriptive text have been published as Hydrologic Investigations Atlases for the following areas during the current year: Highland Park, Ill. (HA–69); Aurora North, Ill. (HA–70); Wheeling, Ill. (HA–71); Fortuna, Calif. (HA–78); Park Ridge, Ill. (HA–85); Palatine quadrangle, Illinois (HA–87); and Raritan and Millstone Rivers in Somerset County, N.J. (HA–104).

ALASKAN EARTHQUAKE

Arthur Grantz, George Plafker, and Reuben Kachadoorian, have completed preliminary geologic evaluation of the March 27, 1964, earthquake in Alaska, based upon a reconnaissance study (2–64).

The earthquake, which had a Richter magnitude variously estimated as between 8.4 and 8.75, was one of the largest in the history of the United States and probably released at least twice the energy of the 1906 San Francisco earthquake. The epicenter of the main shock, which lasted between 1½ and 4 minutes, was in the northern part of Prince William Sound, on the east side of Unakwik Inlet at lat 61.05° N., long 147.50° W. The aftershock zone extended from northern Prince William Sound southwestward as far as southern Kodiak Island. The earthquake and its aftershocks, as suggested by their location and nature, occurred along a fault or broad zone of faulting possibly several hundred miles long and associated with the Aleutian Islands arc and the Aleutian Trench. Preliminary aerial reconnaissance in the area of the epicenter, within the area where the Aleutian fault zone intersects the continent, failed to reveal signs of surface breakage.

Tectonic changes in land level of regional extent occurred on both sides of the fault zone. To the west of the zone an area of at least 22,000 square miles, which includes the Kenai Peninsula and at least the northern part of Kodiak Island, subsided as much as 5.4 feet relative to sea level. To the east of the fault zone there has been tectonic uplift of as much as 7.5 feet over an area of at least 12,000 square miles that includes eastern Prince William Sound, the adjacent mainland, and the continental shelf.

Major losses of life and property were from several types of earthquake-generated waves in coastal areas, and earthquake-triggered submarine and subaerial landslides. Seismic shock, compaction and lurching due to shaking of unconsolidated materials, and rockslides and avalanches also caused significant damage and changes in landscape over more than 50,000 square miles of land area.

A train of seismic sea waves that originated in the Gulf of Alaska was particularly destructive along the tectonically subsided coast of Kodiak Island and at Seward on the Kenai Peninsula. They also resulted in losses of life and property along the coasts of British Columbia, Oregon, and California.

Local waves of unknown origin within Prince Willian Sound struck within minutes of the earthquake, took a total of 31 lives, and virtually wiped out the native village of Chenega.

Submarine landslides, particularly at the waterfronts of Valdez and Seward, destroyed most of the harbor facilities at these two port cities. Waves that immediately accompanied the landslides, and a train of seismic sea waves that followed later, resulted in virtual destruction of the waterfront areas. Submarine landslides also destroyed the small boat harbor at Homer and were reported along the coast as far away as southeastern Alaska, where the Skagway-Haines telephone cable was broken by a slide.

Three large landslides and at least 8 smaller ones located in weak glaciolacustrine clay deposits [33] along the bluffs facing Knik Arm and Ship Creek caused most of the 9 casualties and the extensive property damage in the Anchorage area. The L Street slide, which was 4,000 feet long and 1,150 feet wide at the widest point, and the 4th Avenue slide, which was 2,500 feet long and 1,150 feet wide, moved laterally as relatively coherent masses. A large landslide at Turnagain Heights, 8,000 feet long and 1,200 feet wide, and several smaller slides, broke into narrow slices which rotated as they moved, thereby destroying most structures within the slide areas.

Substantial damage due to seismic shock was sustained by structures in the Anchorage area and to a lesser extent in Seward, Valdez, and Whittier. Highway and railroad bridges from the Copper River to the Kenai Peninsula were also extensively damaged by earth tremors. Damage was most severe to those structures on thick saturated alluvial deposits and markedly less to structures founded on bedrock.

Fissuring and compaction of unconsolidated deposits were widespread, and many of the cracks formed were destructive to structures and earth fills founded on such deposits. The lowered land-surface levels, particularly in coastal areas such as Turnagain Arm and Homer Spit which had also been affected by tectonic subsidence, resulted in subsequent property losses by inundation during high tides.

Lowered water levels in artesian wells were recorded and some surface streams were temporarily reduced in flow following the earthquake, presumably due to local slight increases in porosity caused by shaking. R. M. Waller reports that considerable subsidence of the land surface occurred by compaction of unconsolidated deposits in south-central Alaska during the earthquake. At Homer, for example, the total lowering of land surface with respect to sea level was 4.5 feet. Of this, at least 2.5 feet was due to compaction of unconsolidated sediments, as demonstrated by protrusion of that amount of a well casing that penetrated 468 feet of alluvium and is anchored in the underlying bedrock. The remaining 2 feet of subsidence is ascribed to tectonic causes.

Detailed followup studies on the geologic aspects of the earthquake are now underway by the U.S. Geological Survey, and additional more detailed reports on the geologic implications of the March 27 earthquake will be prepared as these studies are completed.

[33] R. D. Miller and Ernest Dobrovolny, 1959, Surficial geology of Anchorage and vicinity, Alaska: U.S. Geol. Survey Bull. 1093, 128 p.

REGIONAL GEOLOGY

Much of the geologic and geophysical work of the U.S. Geological Survey consists of the mapping of specific areas, mostly for publication in quadrangle maps at scales of 1 : 62,500 and 1 : 24,000. Some of these studies are for the purpose of extending the detailed geologic knowledge in areas of known economic interest; some are to gain detailed knowledge at localities or areas for engineering planning or construction. Still other mapping studies are carried on with paleontology, sedimentary petrology, or some other specialized topic as the primary objective.

The systematic description and mapping of rock units to show local and regional relations likewise constitute a major scientific objective. Mapping the geology of the United States is a mandate of the Organic Act establishing the Geological Survey, and the completion of geologic maps for the country at scales that will fulfill foreseeable needs and uses is a long-range goal. A summary of recent results of this mapping, especially in the fields of stratigraphy, structural geology, and regional geophysics, is discussed here according to subdivisions of the conterminous United States shown on figure 5.

Figure 5.—Index map of the conterminous United States, showing boundaries of regions referred to in discussion of regional geology.

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MAPS OF LARGE REGIONS

The preparation of geological and geophysical maps of national or continental scope is an established part of the work of the U.S. Geological Survey. Such maps synthesize data from other maps and topical studies by Geological Survey personnel, data from published sources, and unpublished data supplied by State geological surveys, private companies, and universities. Some of the maps are prepared and published by the Geological Survey in collaboration with national and international scientific organizations. Maps of large regions currently being prepared in collaboration with other organizations include:

1. Geological map of North America, scale 1:5,000,000. Compilation of this map, which is now completed, was done by a committee of the Geological Society of America, E. N. Goddard, University of Michigan, chairman. A new base map of North America has been prepared by the U.S. Geological Survey, and the geologic map will be published on the new base.
2. Tectonic map of North America, scale 1:5,000,000. This is being compiled for the Subcommission for the Tectonic Map of the World, International Geological Congress, by P. B. King, of the Geological Survey. Preliminary drafts of the map were corrected during 1964. It is planned to show the distribution of tectonic (rather than stratigraphic) map units over all of the continent. A nearly completed version of the map will be on exhibit at the International Geologic Congress in New Delhi, India, at the end of 1964.
3. Basement map of North America from latitude 20° N. to 60° N., scale 1:5,000,000. This map has been compiled by the Basement Rock Committee of the American Association of Petroleum Geologists, P. T. Flawn, University of Texas, chairman. It is to be published by the Geological Survey on the new base map of North America. The basement map will show the altitude of the upper surface of basement rocks as determined from wells, geophysical measurements, and geological inference.
4. Basement rock map of the United States, scale 1:2,500,000. As an outgrowth of the basement map of North America, the Advanced Research Project Agency, Department of Defense, is sponsoring the compilation of a basement rock map of the United States under the direction of W. R. Muehlberger, University of Texas. The map will show subdivisions on the basis of age and lithologic type of the buried basement as well as the altitude of the basement surface by contours. As a companion project, R. W. Bayley, U.S. Geological Survey, is directing compilation of a map of exposed basement rocks showing subdivisions on the basis of age and lithologic type. Trend lines on this map will show some internal structures of the rocks. The two compilations will be combined and published by the Geological Survey.
5. Bouger gravity anomaly map of the United States (exclusive of Alaska and Hawaii) and part of Canada, scale 1:2,500,000. This map has been compiled by the Committee for Geophysical and Geological Study of the Continents, American Geophysical Union, G. P. Wollard, University of Hawaii, chairman, and is being prepared for publication by the Geological Survey.

Paleotectonic maps

A program to compile and publish paleotectonic maps of the conterminous United States for each of the geologic systems is continuing. The maps record geologic events on a nationwide scale and are accompanied by a text that provides documentation and assists interpretation. Interpretive maps reconstruct the former extent of the sediments of the geologic system, the position and relative heights of former land areas, changes in the patterns of sedimentation, environments of deposition, and other features of regional geologic importance. Folios for the Jurassic and Triassic Systems have been published to date. Maps for the Permian, Pennsylvanian, and Mississippian Systems are in various stages of preparation. The Permian maps have been compiled and are being readied for publication. The maps for the Pennsylvanian and Mississippian Systems are being assembled concurrently, and are in preliminary stages of preparation. For purposes of representation on lithofacies and isopach maps, rocks of the Pennsylvanian System are being divided into five map units or intervals corresponding in age in a general way with the Virgil, Missouri, Des Moines, Atoka, and Morrow Series of the midcontinent region. Rocks of the Mississippian System are being divided into four maps units corresponding roughly in age to the Chester, Meramec, Osage, and Kinderhook Series of the central United States.

COASTAL PLAINS

ATLANTIC COASTAL PLAIN

Paleontology of Tertiary deposits

A recent study of the macrofauna and microfauna of the Miocene and Pliocene deposits of the Atlantic Coastal Plain, by T. G. Gibson, has shown the area to be more structurally and stratigraphically complex than formerly thought. Positive features which subdivided the large embayment into smaller elements arose at different times during the Miocene, causing marked differences in environments. Correlation across the positive areas and into the different basins has been accomplished by the use of the more mobile mollusks, such as the Pectinidae, and the planktonic Foraminifera. Subsurface material has yielded the downdip equivalents of many of the surface units, but much of the middle Tertiary, thought to be absent because of lack of surface exposures, is represented in the subsurface.

T. C. Gibson also reports that study of the Mollusca, particularly the Pectinidae, of the Miocene and Pliocene of the Atlantic Coastal Plain has led to the vertical zonation of the deposits. The presence of mobile groups like the Pectinidae in various environments has made possible the correlation of many small outcrops over a large geographic area. Other molluscan groups have also been used to substantiate the zoning.

Cyclic deposition in Cretaceous and Tertiary time

The cyclical nature of the coastal-plain deposits, which range from Turonian through Pliocene(?) in age, in New Jersey and Delaware provides an important clue to the mechanism of deposition for these units. J. P. Owens and J. P. Minard report that this cyclical deposition taken in association with the relatively immature composition of the sediments (primarily feldspathic sands) suggests deposition on a relatively unstable platform. They believe that this interpretation is compatible with the geophysical investigations off the coast of New Jersey by Drake,[34] in which he depicted large downwarps in the mantle relatively close inshore.

Petrography of basement gneiss beneath coastal-plain sequence in New Jersey

D. L. Southwick (p. C55–C60) described the petrography of an 8-foot core taken 3,873 to 3,881 feet below the land surface and about 75 feet below the base of the sedimentary rocks of the coastal plain at Island Beach State Park, N.J. The core consists of strongly foliated garnet - microcline - biotite - quartz - plagioclase veined gneiss close to migmatite in structure. A K–Ar age of 235 million years suggests recrystallization during the late Paleozoic metamorphic event that affected parts of southeastern New England.

Subsurface stratigraphy at Cape May, N.J.

Significant zones and horizons were recognized in a cursory examination of samples from Dickinson test well 1, Cape May, N.J., by H. R. Berquist and J. E. Johnston. Samples in the top 920 feet were largely barren of micro fossils and consisted mainly of conglomeratic sands, suggestive of channel or estuary fill.

Tertiary rocks are represented by Paleocene, lower to upper Eocene, and Miocene beds. The top of Upper Cretaceous was tentatively identified at 1,980 feet.

H. R. Bergquist recognized a thin but significant zone of charophytes. From a comparison with published material by Peck,[35] the utricles and gyroganites were tentatively identified as *Atopochara trivolvis* Peck and were judged to be of very early Cretaceous (Aptian) age. Subsequently, the find was verified through Esther Applin, who had submitted specimens from this well to Raymond E. Peck and was informed that so far as is known this fossil is confined to the Aptian, though it has worldwide distribution. More significantly this may indicate downwarping, and (or) eustatic change of sea level, of nearly 4,500 feet since Early Cretaceous, as the charophytes are nonmarine aquatic plants. Their occurrence in the subsurface could be explained by post-depositional slumping into a nearshore deep, or less likely, by fresh-water upwelling on the shelf during the Cretaceous.

The top of the "granite wash" was identified at approximately −6,130 feet, the top of the saprolite zone at −6,370 feet, and the top of the basement complex at −6,400 feet, sea level datum.

High gravels of Maryland yield Cretaceous spores

Identification of fossil spores by Jack Wolfe in peat interbedded with high-level gravels (Bryn Mawr and Brandywine Gravels) of Cecil and Harford Counties, Md., indicates an Early Cretaceous age for these gravel beds now considered Pliocene(?) in age.

[34] C. L. Drake, W. M. Ewing, and G. H. Sutton, 1959, Continental margins and geosynclines—the east coast of North America north of Cape Hatteras, *in* L. H. Ahrens and others, eds., Physics and chemistry of the earth, v. 3: London, Pergamon Press.

[35] R. E. Peck, 1957, North American Mesozoic Charophyta: U.S. Geol. Survey Prof. Paper 294–A.

Age of basement schist in south-central New Jersey

Recent K–Ar age determination of mica schist recovered at 2,078 feet below land surface from a Geological Survey core hole at New Brooklyn Park, Camden County, N.J., gave an age of 301 million years according to analysts H. H. Thomas, R. F. Marvin, Paul Elmore, and Hezekiah Smith. More age determinations are needed in the vicinity before meaningful interpretation can be made.

Cretaceous fossils from Chesapeake and Delaware Canal

N. F. Sohl's analysis of Upper Cretaceous fossils from the Chesapeake and Delaware Canal documents the presence of Merchantville, Marshalltown, and Mount Laurel faunas. Contrary to published record, no Red Bank or Navesink faunas are present along the canal. The Merchantville Formation can be correlated with the lower part of the Blufftown Formation of Georgia and the lower part of the Coffee Sand of Mississippi. The Mount Laurel Sand is equivalent to the upper part of the Cussetta Sand of Georgia, the upper part of the Bluffport Marl Member of the Demopolis Chalk of Mississippi, and the lowermost part of the Ripley Formation of Tennessee.

Foraminifera date zone of Marshalltown Formation

The Upper Cretaceous Marshalltown Formation near the top of the Matawan Group, is exposed at Auburn, Del., where it contains abundant specimens of *Exogyra ponderosa* (Roemer) and *Ostrea* species. This locality yielded an abundant foraminiferal fauna consisting of 30 identified species, 8 of which are planktonic. Comparison of these Foraminifera, by J. F. Mello, J. P. Minard, and J. P. Owens with the age ranges of the same species on the Gulf Coast suggests that the sample is of late Taylor age (p. B61–B63).

Eocene to Recent offshore stratigraphy of Georgia

Working with rock cores and cuttings from two test holes about 10 miles offshore from Savannah Beach, Ga., M. J. McCollum and S. M. Herrick (chapter D) found that upper Eocene to Recent stratigraphic sequence is similar to that onshore, but that the post-Miocene section is thinner.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT

Geologic mapping and stratigraphic studies in the Jackson Purchase area, Kentucky

Geologic mapping and stratigraphic studies in the Jackson Purchase area (the part of Kentucky west of the Tennessee River) have added substantially to the knowledge of the stratigraphy and areal distribution of Mesozoic and Cenozoic rocks in the northern Mississippi Embayment, and of the structural framework of the area. Stratigraphic investigations have been greatly enhanced by palynological studies by R. H. Tschudy, Estella B. Leopold, and Helen Pakiser.

Mapping by T. W. Lambert (1–63), W. W. Olive (1–63), H. G. Wilshire (1–63, 2–63), and E. W. Wolfe (1–63) has shown that the Tuscaloosa and McNairy Formations (Upper Cretaceous), the basal units of the embayment sequence, rest on an intricately eroded surface of considerable relief developed on Mississippian rocks composed for the most part of residual chert and clay derived from leaching of limestone. The Tuscaloosa Formation, composed dominantly of chert gravel and tripolitic silt, occurs as scattered lenses, as much as 150 feet thick, that fill the deepest pre-Tuscaloosa channels. The McNairy Formation comprises about 200 feet of sand that contains widely spaced clay lenses. It unconformably overlies the Tuscaloosa Formation and overlaps the Mississippian rocks.

The Clayton Formation (Paleocene) is composed of clay and sand deposits that closely resemble those of the upper part of the McNairy Formation. For this reason, and because the Clayton is poorly exposed, the two units have been combined for purposes of mapping in the Jackson Purchase area. Evidence from field observations, palynological studies by Tschudy of samples collected by W. W. Olive from the western part of the Hico quadrangle, and subsequent unpublished palynological studies indicates that deposition in Kentucky was continuous from the Cretaceous into the Tertiary and was not interrupted by an hiatus as L. W. Stephenson [36] contended.

The Porters Creek Clay, 150 to 250 feet thick, is composed dominantly of montmorillonitic clay but commonly is sandy in the upper and lower parts. This unit, which with the Clayton Formation makes up the Midway Group (Paleocene), conformably overlies the Clayton Formation throughout most of the area, as studies by L. V. Blade (1–63), W. W. Olive, and E. W. Wolfe (1–63) suggest; however, W. I. Finch reports an unconformity between the two units in the Symsonia quadrangle in the northern part of the area.

A sequence consisting of as much as 165 feet of interbedded argillaceous sand, sandy clay, and lignite above

[36] L. W. Stephenson, 1915. The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U.S. Geol. Survey Prof. Paper 90–J, p. 155–183.

the Porters Creek Clay lithologically resembles sediments of the Wilcox Group in Mississippi. On the basis of lithologic similarity and of palynological evidence provided by E. B. Leopold, Helen Pakiser, and R. H. Tschudy the sequence is tentatively designated as the Wilcox Formation (lower Eocene). The unit is discontinuous at the outcrop, because of overlap by younger Eocene sediments. In the Kirksey (Wilshire, 2–63), Dexter (Wolfe, 1–63), Hazel (Blade, 1–63), and Symsonia quadrangles the areal distribution of the Wilcox(?) suggests that it was deposited in shallow depressions eroded into the underlying Porters Creek Clay.

A unit dominantly composed of sand and scattered clay lenses tentatively designated as the Claiborne Group (middle Eocene) by W. W. Olive overlies with marked unconformity the Wilcox(?) Formation and Porters Creek Clay. In the Lynn Grove quadrangle the unit is as much as 200 feet thick (Olive, 1–63). Westward, the Claiborne (?) is overlain by lithologically similar but younger deposits that on the basis of palynological evidence provided by Tschudy (Blade, 1–63) may be as young as Oligocene or Pliocene in age. Owing to lithologic similarity, scarcity of palentologic information, and very poor exposure, the younger deposits cannot be differentiated from the Claiborne(?); therefore, these sediments have been grouped by Blade (1–63), Finch (1–63), and Wilshire (2–63) into one unit that is designated "coastal plains deposits."

Surficial deposits ranging from Pliocene(?) through Recent, in age, blanket older rocks, concealing them over extensive areas. The oldest unit of these surficial deposits consists of gravel, sand, and clay as much as 100 feet thick, and is designated "continental deposits." Leopold and Pakiser conclude that pollen from a clay sample collected by T. W. Lambert from such deposits in the Lynnville quadrangle is Pliocene or younger in age. Loess of Pleistocene age, which ranges in thickness from 1 or 2 feet in the easternmost of the mapped quadrangles to 26 feet in the westernmost, generally overlies the continental deposits; and alluvium of Recent and Pleistocene age and as much as 142 feet thick (L. N. Baker, 1–63) fills the stream valleys. Studies of valley deposits along the Ohio and Tennessee Rivers by W. I. Finch, W. W. Olive, and E. W. Wolfe (p. C130–C133) indicate the existence of an ancient lake of probable late Pleistocene age.

A study of the thickness and size distribution of gravel deposits and of the configuration of the surface developed on rocks beneath the surficial deposits suggests that the continental deopsits entered the Jackson Purchase from the southeast and poured onto a gently northward and westward sloping surface of low relief that rose to an altitude slightly above 500 feet in the southeastern part of the area. In some areas the surface is traversed by narrow deeply incised channels, filled with continental deposits. These channels reflect increased precipitation and rapid lowering of base level that accompanied the deposition of the continental deposits. Subsequent to deposition, probably during glacial epochs, the continental deposits in some areas were worked and redeposited at lower elevations.

Northeasterly and northwesterly trending faults with displacements of as much as 150 feet displace rocks as young as Pliocene(?) and Pleistocene in age in parts of the Jackson Purchase area.

Relation of clay mineralogy to depositional environment in Upper Jurassic shale, northeastern Texas

K. A. Dickson has recognized a relation of clay mineralogy to depositional environment in shale of Late Jurassic age in Bowie and Cass Counties, northeastern Texas. The nonmarine "pastel" shale which contains illite and kaolinite grades into dark-gray or black offshore marine shale containing illite and iron-rich chlorite. Intermediate nearshore shale contains a mixture of illite, kaolinite, and chlorite.

Caloosahatchee beds of Florida believed to be Tertiary

A newly discovered outcrop of the Pliocene Caloosahatchee Formation on Shell Creek, in Florida, west of the late Miocene "Buckingham arch," is reported by Druid Wilson. A previously known outcrop in North Ft. Myers no longer exists. Both localities produced specimens of a new species of the extinct pelecypod genus *Agnocardia*, previously known from beds no younger than the middle Miocene of Jamaica. The presence of *Agnocardia* in the Caloosahatchee supports a Tertiary rather than Pleistocene age for these beds.

NEW ENGLAND AND EASTERN NEW YORK

Geologic map of New England compiled

A preliminary geologic map of New England has been compiled by Richard Goldsmith (1–64), based on much recent detailed mapping and unpublished information. The geologic map is supplemented by maps that show metamorphic zones and radiometric ages.

MAINE

Eastern border of "ribbon rock" facies located

Continuing work by R. B. Neuman (1–64) on collections of Ordovician brachiopods from Maine and adjacent provinces of Canada has revealed additional European genera. However, a collection from Blue Bell, New Brunswick, yielded none of these, but does contain *Zygospira*, a genus common in North America but rare in Europe. The rocks from which this collection came are of the same age as at least part of the "ribbon rock" of Aroostook County and bordering New Brunswick, and thus the eastern boundary of that facies lies not far east of the international boundary.

Structural history of Katahdin pluton

A breccia zone as much as a mile wide has been found by R. B. Neuman in the Stacyville quadrangle in north-central Miane, along a 20-mile segment of the eastern and southeastern margin of the Katahdin pluton. The breccia consists of fragments, as much as tens of feet across, of metamorphosed and partially assimilated fine-grained sedimentary rocks in a matrix of granite or quartz monzonite. The Katahdin magma is believed to have stoped its way upward along a moderately inclined eastward-dipping surface across the steep structures of the sedimentary and volcanic units of the area. Apparently pure, fossiliferous Upper Silurian reef limestone was found through an area of about half a square mile, a mile east of the Katahdin pluton near the middle of the quadrangle. This limestone is interpreted to lie in a fault wedge that is part of the fault system followed by the East Branch of the Penobscott River in this area.

Anticlinorium recognized in Maine and New Brunswick

An extensive belt of limy rocks, thought to be Silurian by earlier workers, is of Middle to Upper(?) Ordovician age, according to Louis Pavlides and others (p. C28–C38), and extends from the Smyrna Mills quadrangle eastward and thence north and northeastward across northeast Maine. On the basis of reconnaissance and on mapping in Canada by a Canadian geologist, it appears that this Ordovician belt extends more or less continuously from Maine across northern New Brunswick and the southern part of the Gaspé Peninsula to Gaspé. Thus, it appears to form the core of a heretofore unrecognized anticlinorium, in the northern Appalachians, which is to be named the Aroostock-Matapedia anticlinorium.

Tectonic activity in Aroostook County

The northeast nose of a large anticline that lies to the northwest of the Aroostook-Matapedia anticlinorium has been mapped by Louis Pavlides in the Howe Brook and Smyrna Mills quadrangles, Aroostook County. On the northwest flank of this anticline is a discontinuous Silurian unit about 1,000 feet thick that contains brachiopods and corals. On the southeast side of the anticline a thick (probably exceeding 5,000 feet) sequence of quartzite, siltstone, and slate contains at least 18 graptolite localities that range from early Llandovery to early Ludlow in age. The contrast between the shelly fauna on the northwest flank of the anticline and the graptolitic fauna on the southeast flank suggests that this anticline acted as a positive landmass during most of Silurian time and strongly influenced the sedimentary and biologic regimen of the region. Local uplift along its northwest flank in Silurian or Early Devonian time has been recognized from reworked Silurian shelly faunas and clasts of Ordovician rocks that were apparently shed from this anticline and incorporated in the basal beds of the Seboomook Formation (Early Devonian age).

Plant fossils were found by Louis Pavlides in the Howe Brook quadrangle at two localities. At one locality they have been recognized as of the psilophyton type and of Devonian age. Mapping indicates they are in rocks equivalent to the Chapman Sandstone of Early Devonian (New Scotland) age that occurs to the north in the Presque Isle quadrangle.

Plant fossils date Acadian orogeny in northern Maine

Identification of psilophytic plant fossils from the Mapleton Sandstone of northern Maine by J. M. Schopf (chapter D) indicates that the Mapleton, which was not deformed during the Acadian orogeny, is of early Givetian (Middle Devonian) age. The collections included new species described as *Barrandeina*(?) *aroostookenis* and *Calamophyton forbesii; Calamophyton* has not been previously reported in North America. This new work appears to bracket the beginning of the Acadian orogeny between the deposition of the Champman Sandstone (Early Devonia) and the Mapleton.

Ostracodes date "nubbly beds" of Aroostook Limestone

The "nubbly beds" of the Aroostook Limestone of Maine have been dated as Silurian (Clinton) by Jean Berdan's discovery in them of ostracodes belonging to the genera *Zygobolba*, *Apatobolbina*, and *Bolbineossia.*

Formerly these beds were considered to be possibly of Late Ordovician age.

Two types of schistosity found in western Maine

Schistosity in the Rangeley quadrangle, Franklin County, is the end product of two contrasting processes, according to R. H. Moench. Pervasive earlier schistosity developed with advancing metamorphism from slaty cleavage, which originated at shallow depths when deformation of newly deposited sediments began. The slaty cleavage formed by flattening and dewatering of sediments at high pore pressures, and was accompanied at places by the formation of sedimentary dikes, where pore pressures were momentarily equal to lithologic pressures. Later, schistosity developed locally at the expense of a widespread slip cleavage and is a product of shearing and recrystallization at a relatively late stage in the tectonic history of the area.

Structure of the Moxie mafic pluton

Continuation of study of the Moxie mafic pluton by G. H. Espenshade shows that it is at least 50 miles long. It is 1 to 2 miles wide over much of this distance, but is 6 to 9 miles wide on the east side of Moosehead Lake, in Piscataquis County, where a gravity high suggests the site of a major feeder. The pluton is possibly an enormous irregular dikelike mass; it is not a simple layered body, but may be a complex of several intrusions. It must have been emplaced in a fluid state because cataclastic structure is rare, occurring only locally with faults. Mineral composition ranges from troctolite, to olivine-rich norite and gabbro, to olivine-free norite and gabbro. No regular pattern of compositional variation is evident. Probable flow structure is common; compositional layering is very rare. Pyrrhotite with a little nickel and cobalt occurs at several places; exploration has failed to find deposits of minable size. Age determination (K–Ar) of biotite by Henry Faul indicates an Early Devonian age for the pluton.

Exploration target in west-central Maine

Stream-sediment sampling on a tributary of Bean Brook in Somerset County, Maine, by F. C. Canney and E. V. Post (chapter D) indicates a metallic anomaly well above average for the region. Analysis of samples of active stream sediment showed lead and zinc contents as high as 2,500 and 7,000 parts per million, respectively. Known exposures of galena- and pyrite-bearing vein quartz are inadequate to account for the intense anomalies.

Heavy-metal anomalies in southeastern Maine

A geochemical map (VanSickle, Dennen, and Post, 1–64), based on colorimetric analyses of 1,100 samples of stream sediment from southeastern Maine, outlines an area of numerous copper and heavy metal (copper, lead, zinc) anomalies in a belt 18 miles wide east of the Penobscot River and extending northward from Blue Hill. These anomalies appear to be related to large masses of porphyritic granite of Devonian age, as well as to smaller bodies of pink biotite granite. The discovery of this belt of anomalies opens up an extensive area for mineral exploration, which heretofore has been directed principally toward coastal Maine.

Heavy-metal anomalies related to Katahdin batholith

Rechecking by E. V. Post and W. H. Dennen of some geochemical anomalies shown on a recent map (Post and Hite, 1–63) confirms the existence of several significant heavy-metal (copper, lead, zinc) anomalies in the Rainbow Lake–Nahmakanta Lake region, in the Harrington Lake quadrangle, eastern Piscataquis County, Maine. This region is part of a larger province in the southwestern part of the Katahdin granite batholith which has a relatively high metal content as compared to the rest of the batholith. Extensive topographic trenches suggestive of large faults in the geochemically anamalous area make it of greater than average interest for mineral exploration.

Three Wisconsin glaciations recognized

Maine may have been glaciated at least three times during Wisconsin time, according to G. C. Prescott, Jr. The principal evidences for multiple glaciation are till of two different ages and differences in directions of glacially produced lineations. The last glaciation probably occurred less than 12,000 years ago.

MASSACHUSETTS

Units correlated in Green Mountain anticlinorium

The Cambrian(?), Ordovician, Silurian and Devonian metamorphic rocks of the east flank of the Green Mountain anticlinorium are being mapped in the Heath quadrangle, northwestern Franklin County, by N. L. Hatch, Jr. Efforts to trace the Vermont section south into Massachusetts indicate that the Pinney Hollow, Stowe, and possibly Ottauquechee Formations are not continuous across the State line, although similar rocks at the same stratigraphic positions are present to the south. Many excellent exposures of the Taconic unconformity are present in the area.

The Cambrian and Ordovician stratigraphy east of the southern extension of the Green Mountain anticlinorium has also been delineated in the Windsor quadrangle, Berkshire County, by S. A. Norton. There is evidence that the Ottauquechee Formation lenses out toward the south, and there is no distinct boundary between the Pinney Hollow and Stowe Formations, two units whose distinction from each other was based on the intermediate position of the graphitic schists and black quartzites of the Ottauquechee Formation.

Deformation dated in southwestern Massachusetts

A major unconformity separating Wilderness and Trenton rocks from older rocks has been established by E-an Zen in southwestern Massachusetts. In the Bashbish Falls quadrangle, rocks as old as unit 2 of the Stockbridge Limestone (Zen, 1–64) are adjacent to the post-unconformity rocks. This observation is consistent with findings in Vermont where the same unconformity cuts down locally to the Precambrian basement. An episode of early, major deformation of the Stockbridge Limestone involves large-scale isoclinal recumbent folding. Several large-scale, apparently geometrically independent, structural elements, perhaps separated by thrust faults, exist in the Stockbridge, and may be related to the early deformation, which in turn may well prove to be preunconformity. An isotopic age of 360–390 million years was obtained from porphyroblastic biotite and muscovite from a Berkshire Schist outcrop in the Bashbish Falls quadrangle. This age corresponds to the growth of the mica crystals, and also to the last known episode of major deformation. Therefore, the age determination casts doubt on the importance or even existence of an episode of regional retrograde metamorphism, postulated for these parts by numerous past workers.

Ayer Granite dated near Worcester coal mine

R. E. Zartman and R. F. Marvin have reported radioactive ages for samples collected by G. L. Snyder in east-central Massachusetts. The Millstone Hill body of Ayer Granite has a whole-rock age of 355 ± 10 million years. The Upper Devonian(?) age of emplacement of this body of Ayer Granite is of interest in that the granite crops out a quarter of a mile from a reported Pennsylvanian fossil locality at the Worcester coal mine. A new collection of fossil plant remains from this area tends to confirm the Pennsylvanian age, according to J. M. Schopf. Possibly the fossiliferous rocks are restricted to the area of the coal mine and are unconformable on the Ayer Granite. A muscovite K–Ar age of 242 m.y. on this granite suggests that some late Paleozoic thermal activity also affected this area.

Three flows recognized in Deerfield Diabase

The Deerfield Diabase in the Triassic rocks at Greenfield, hitherto considered to be 1 flow, has been shown by Andrew Griscom to consist of at least 3 flows with rather different magnetic properties and directions of remanent magnetization.

Shelburne Falls dome found to be funnel shaped

Preliminary analysis by R. W. Bromery of aeromagnetic and gravity data in the area of the Shelburne Falls dome of Franklin County indicates that the low-density magnetic rock mass of the dome is funnel shaped with thickest section at its southeastern end. The northeast lobe of the mass is probably a spoon-shaped body whose central part is approximately 4,000 feet thick.

Basement surface mapped on Cape Cod

Interpretation of seismic measurements in the Harwich and Dennis quadrangles on Cape Cod by R. N. Oldale discloses an eastward-trending basement ridge composed of crystalline rocks of Paleozoic age or older, with compressional speeds of 14,100 to 22,000 feet per second. The altitude of the basement surface ranges from about 180 to 560 feet below sea level, and the maximum depths occur in four south-sloping valleys. Three seismic layers distinguished above the basement are believed to consist of an upper layer of unsaturated stratified drift, a middle layer of saturated stratified drift and minor amounts of till, and a lower layer of compact till and possibly minor amounts of coastal plain deposits of Tertiary or Mesozoic age.

Seismic studies elsewhere on Cape Cod by R. N. Oldale and C. R. Tuttle (1–64) show that crystalline basement rocks are overlain by Pleistocene, Tertiary, and possibly Mesozoic deposits that range from 250 to possibly more than 960 feet in thickness. A trough in the basement surface extending to about 900 feet below sea level was found on outer Cape Cod near Truro.

Other seismic studies in Massachusetts are described in the section "Engineering Geology."

Glacial units delineated in southeastern Massachusetts

Six drifts and the deposits of one interglaciation have been recognized on Martha's Vineyard by C. A. Kaye (p. C134–C139). It is thought that they represent Nebraskan Glaciation, Aftonian Interglaciation, and Kansan, early and late Illinoian, and early and late Wisconsin Glaciations. Periglacial effects of the middle Wisconsin Glaciation, whose terminal moraine is nearby at the Elizabeth Islands, are also evident. The stratigraphy, which is very much complicated by severe ice thrusting, is remarkably similar to that worked out by Fuller and Woodworth half a century earlier.

Three of these drifts of Martha's Vineyard are in part terminal moraines, according to Kaye (p. C140–C143). The oldest is a fragmentary early Illinoian moraine. The hills and valleys of the western part of the island are the eroded remains of a very large moraine pushed up by late Illinoian ice. Early Wisconsin ice generally stopped against the high late Illinoian moraine, but built an extensive moraine in the eastern part of the island.

Studies of till in the Taunton quadrangle of southeastern Massachusetts by J. H. Hartshorn show that it is possible to distinguish between flowtill (a superglacial till) and subglacial till by stone counts, in addition to the usual criterion of position in or on ice-contact stratified drift. The proportion of rock types from the Narragansett basin, within which the quadrangle lies, relative to that of rock types from north of the basin, increases southward within the quadrangle in subglacial till, but decreases southward in flowtill.

Three readvances of last glaciation in Boston area

According to C. A. Kaye, the retreat of the last ice sheet across the Lynn quadrangle, just north of Boston, was characterized by at least three readvances, each falling short of the maximum extent of the previous one. The direction of ice flow was different for each readvance and it is this fact that made possible the recognition of this retreatal pattern. Glacial striations of each of three main azimuths are grouped into oblate belts, which also correlate with the distribution of outwash deposits. The readvances probably mark climatic fluctuations of periods of less than a century.

Pleistocene beaches recognized

Pleistocene marine beaches ranging in altitude from present-day sea level to 70 feet above sea level have been recognized in the Newburyport East quadrangle in northeastern Massachusetts by J. E. Cotton. Drilling evidence indicates that these beaches are underlain by 30 to more than 50 feet of marine clayey silts.

Glacial lake deposits

The Boylston, Clinton, and Ayer stages of glacial Lake Nashua have been outlined by Carl Koteff in the Clinton quadrangle, Worcester County, virtually as by previous workers. However, the Leominster stage is recognized as a separate glacial lake about 80 feet higher than the Clinton stage. Lake Leominster came into existence after the Clinton stage, and was completely drained before the lowering of Lake Nashua from the Clinton stage to the Ayer stage.

Deposits of glacial Lake Bascom in the Williamstown area of northwestern Massachusetts include silt, clay, and delta gravel. The laminated silt and delta gravel occur mostly at the level suggested by F. B. Taylor to be the highest and most prominent shoreline, about 1,125 feet above sea level. Blue and yellow clays occur mostly below about 950 feet above sea level, and as deep as 116 feet below the flood plain of the Hoosic River at Williamstown (or about 485 feet above sea level). The clays are interbedded with and overlain by coarse gravel, probably glaciofluvial in origin; this suggests several generations of lake deposition, alternating and concluding with stream deposition.

RHODE ISLAND

Geologic map of Rhode Island completed

A preliminary geologic map of Rhode Island has been compiled by A. W. Quinn (1–64). The major groups of rocks include metasedimentary rocks of the Blackstone Series of Precambrian(?) age, metasedimentary rocks of middle Paleozoic age or older, very widespread plutonic rocks of Mississippian(?) age or older, granites and volcanic rocks of the East Greenwich Group of Mississippian(?) age, sedimentary rocks of Pennsylvanian age in the Narragansett basin, and granites of Pennsylvania age or younger.

Feldspathization widespread in metamorphic rocks

According to Tomas Feininger, extensive feldspathization of schists derived from pelitic rocks has been an important process in southwestern Rhode Island. Feldspathization was the result of alkali metasomatism from granitic magmas during and immediately following intrusion. The effects of this process are visible in the gneissic granitic rocks which ultimately crystallized from the magmas as well as in the metasomatites.

Absalona Formation believed igneous

Abundant inclusions of different lithologic character in the Absalona Formation in the Clayville quadrangle, west of Providence, mapped by G. E. Moore, Jr., indicate that this formation is possibly igneous in origin. The lithology of the formation is similar to that of the probably magmatic quartz diorite gneiss of the quadrangle.

Late Paleozoic igneous relations clarified

Reports on two adjacent areas, the Coventry Center quadrangle, by G. E. Moore, Jr. (1–63), and the Crompton quadrangle, by A. W. Quinn (1–63), cover an area southwest of Providence that is almost entirely underlain by the Scituate Granite Gneiss and related rocks. These plutonic rocks show evidence of magmatic origin, and are of Mississippian(?) age or older. Still older are small bodies of metasedimentary rocks. Mississippian(?) granite and volcanic rocks of the East Greenwich Group underlie much of the eastern part of the Crompton quadrangle, which also contains a very small area of the Pennsylvanian sedimentary rocks of the Narragansett basin. The rocks of these quadrangles were affected by at least two and perhaps three periods of metamorphism, the last of which followed the deposition of the Pennsylvanian rocks. The gabbro of the northwestern part of the Coventry Center quadrangle is unmetamorphosed, and possibly is younger than the time of metamorphism of the Pennsylvanian rocks.

Extensive moraine mapped across Rhode Island

A discontinuous morainic line in southwestern Rhode Island and southeastern Connecticut extends almost 50 miles north-northeastward, according to recent mapping and reconnaissance by J. P. Schafer. The line includes to the east the short moraine segments mapped by earlier workers near Kingston, R.I., and to the west the two closely parallel moraines recently mapped by Goldsmith near Niantic, Conn. This morainic line lies about 4 miles south of the similar Ledyard moraine [37] and 5 to 9 miles north of the much larger Harbor Hill–Charlestown moraine.

CONNECTICUT

Tunnel mapping provides new information on Triassic rocks near Hartford

The geology of the mile-long Talcott Mountain Tunnel in the Avon quadrangle, west of Hardfort, was mapped by R. W. Schnabel. The tunnel exposed a complete section through the upper part of the New Haven Arkose (siltstone and sandstone), the Talcott Basalt, the Shuttle Meadow Formation (77 feet thick, nearly all siltsone), and the lower part of the Holyoke Basalt. The Talcott Basalt, 180 feet thick, is a heterogeneous mixture of basalt and basalt-sandstone breccia, and may be composed of several flows. The Holyoke Basalt, 330 feet of which is exposed in the tunnel, is massive to prismatically jointed, and contains in the upper part of the exposure a red vesicular and amygdaloidal zone that indicates that here the Holyoke Basalt consists of at least two flows.

Gabbro body near Lebanon outlined

Geologic and gravity studies by M. F. Kane and G. L. Snyder (p. C22–C27) have shown that the discordant gabbroic instrusive body near Lebanon, Conn., is a northeast-trending boat-shaped mass 10 miles long, 2 miles wide, and 3,000 feet deep attached by its stern to a dominantly northwest-trending curved sheet 15 miles long and as much as ½ a mile wide.

Gneissic granitic rocks recognized as magmatic

Evidence from the Ashaway and Voluntown quadrangles, along the Connecticut-Rhode Island border, mapped by Tomas Feininger, strongly suggests that the gneissic granitic rocks of the area were intruded as magma. Some of the more silicic granites contain layers of nodules, from 1 to 15 cm in diameter, of quartz-sillimanite, or quartz-muscovite-sillimanite. The layers of nodules are believed to reflect highly peraluminous domains within a magma which had an overall peraluminous composition.

Igneous events dated in eastern Connecticut

R. E. Zartman and R. F. Marvin have reported several useful radioactive ages for rock and mineral samples collected by G. L. Snyder and H. R. Dixon in eastern Connecticut. The premetamorphic Canterbury Gneiss and related rocks and a postmetamorphic pegmatite have been dated directly, and a minimum age has been obtained for the gabbro of Lebanon. The Canterbury Gneiss gives a Rb-Sr whole-rock age of 405± 20 million years as its time of emplacement, and a related granite dike has a Rb-Sr whole-rock age of 390±20 m.y. This granite dike transects, and contains, schlieren of the gabbro of Lebanon, indicating that the gabbro was emplaced before 390 m.y. ago. The strontium in the granite underwent isotopic homogenization during a metamorphism 285 m.y. ago, and its muscovite gives a 237 m.y. K–Ar age. In the area of the Willimantic dome, muscovite in an unmetamorphosed pegmatite has a Rb–Sr age of 245 m.y.

Periglacial features in northeastern Connecticut

An exposure of a polygonal network of late-glacial ice-wedge structures in glacial outwash at Thompson, in northeastern Connecticut, was studied by J. P. Schafer. Individual structures have been seen at other localities, but this is the first known network in New

[37] Richard Goldsmith, 1960, A post-Harbor Hill–Charlestown moraine in southeastern Connecticut: Am. Jour. Sci., v. 258, p. 740–743.

England, and it confirms the existence of permafrost conditions as the last ice sheet retreated.

ADIRONDACK MOUNTAINS

Phacoliths ascribed to metasomatism

Work by A. E. J. and Celeste G. Engel[38] indicates that the 14 phacoliths in the northwest Adirondack Mountains are products of large-scale granitic and mafic metasomatism. The parent rock was a thick calcareous quartzite at the base of the exposed Grenville sequence. Both granitization and amphibolitization of beds in this quartzite accompanied its deformation into complex and refolded folds. The flanks of the phacoliths are commonly a plagioclase-rich granitic rock with numerous amphibolite interlayers; both of these rocks grade laterally into quartzite and calcareous quartzite. The end product of metasomatism is alaskitic granite with scattered interlayers of amphibolite; these rocks form the cores of the phacoliths and appear in the crests of the folds and diapiric domes. At least 120 cubic miles of the phacoliths is demonstrably of metasomatic origin. The proof lies in the complicated patterns of relict bedding in granite and amphibolite. This bedding forms a distinctive stratigraphic sequence that may be traced from phacolith to phacolith throughout an area of 1,200 square miles. Analagous "phacoliths" appear in the southwest and southern Adirondacks. Very probably, more than three-fourths of the granitic rock in the northwestern and southern Adirondacks, outside the central massif, is of metasomatic origin; an equivalent percentage of the layered amphibolites in the same regions is formed by mafic metasomatism and metamorphic differentiation along beds of initially quite different sedimentary composition.

Gravity anomaly mapped near Lake Champlain

Local gravity highs near Chateaugay and Ellenburg, N.Y., Jericho, Vt., and Plattsburgh, N.Y., are roughly alined along a regional gravity arch which strikes approximately west-northwest and intersects the Appalachian structural trends at a high angle, according to W. H. Diment (1–64). The centers of the largest gravity (25 milligals) and magnetic (2500 gammas) anomalies nearly coincide, about 4 miles north of the center of Plattsburgh, N.Y. The area is covered by Cambrian and Ordovician sedimentary rocks, and the rocks causing the anomalies are not exposed. The tops of the shallowest anomalous rocks are no more than several thousand feet below the surface, but because the thickness of the Paleozoic rocks is of the same order, it cannot be determined from the available data whether the anomalous rocks intrude the Paleozoic sedimentary rocks or whether they are wholly contained in the Precambrian basement rocks. The trend of the anomalies parallels that of the Monteregian Hills 50 miles to the north, and the local anomaly at Plattsburgh resembles the anomalies caused by the more mafic intrusions of alkalic rocks that form the Monteregian Hills. Therefore, the anomalies may be the expression of subsurface intrusives of the Monteregian type.

Glacial lake deposits in Lake Champlain area

In the region near Plattsburgh, N.Y., a moraine built on west side of an ice lobe in the Champlain Valley during later Wisconsin time dammed large valleys, such as the Saranac River valley, that drain northeastward from the mountains, according to C. S. Denny. Nonglacial waters from these valleys flowed along the edge of the ice and swept away large masses of moraine, leaving broad expanses of bare rock, locally cut by small canyons. The withdrawal of the edge of the Champlain Valley ice lobe from the moraine initiated small marginal lakes. The deposits formed in these lakes were formerly believed to have been deposited in a proglacial lake that filled the Champlain Valley, named the Coveville stage of Lake Vermont. Further withdrawal of the Champlain Valley ice lobe led to formation of one large lake, the Fort Ann stage of Lake Vermont of Chapman.

APPALACHIAN REGION

STRATIGRAPHIC STUDIES

Most current stratigraphic studies in the Appalachian region are being done in the Valley and Ridge province, but progress is being made also in the stratigraphy of parts of the Blue Ridge and Piedmont provinces.

Revision of Helderberg Group in New York and Virginia

Continued work by J. M. Berdan (1–64) on the Helderberg Group of east-central New York supports previous work by L. V. Rickard, of the New York State Geological Survey, showing that the type Manlius Limestone is of Devonian rather than Silurian age and belongs in the Helderberg Group. The previously accepted Silurian age for at least part of the formation was based on miscorrelation with beds in other areas

[38] A. E. J. Engel, and C. G. Engel, 1963, Metasomatic origin of large parts of the Adirondack phacoliths: Geol. Soc. America Bull., v. 74, p. 349–354.

actually equivalent to the underlying Cobleskill Limestone.

In the Valley and Ridge province, work on a similar problem by R. L. Miller, L. D. Harrris, and J. B. Roen (p. B49–B52) in Scott, Wise, and Lee Counties, southwestern Virginia, has shown that a unit of abundantly fossilferous calcareous sandstone 40 to 45 feet thick lies disconformably on the Hancock Limestone (or Dolomite) of Silurian age and disconformably beneath the Chattanooga Shale of Late Devonian and Early Mississippian age. At its type locality in the Big Stone Gap area the sandstone seems to be entirely of Helderberg age, but its upper part in several other places contains beds that are of Oriskany and Schoharie ages. These post-Helderberg rocks are probably remnants of a more extensive but thin layer of late Middle Devonian sediments only locally preserved from pre-Chattanooga erosion.

Conodonts suggest correlatives of Big Stone Gap Shale Member of Chattanooga Shale, Virginia

J. W. Huddle's discovery of the conodont, *Spathognathodus anteposicornis* in the lower part of the Big Stone Gap Shale Member of the Chattanooga Shale of southwest Virginia (Roen and others, p. B43–B48) suggests a correlation with the Bedford Shale of Ohio, Knapp and Riceville Formations of northwest Pennsylvania, and the Louisiana Limestone of the Mississippi Valley. This conodont species is characteristic of the *Gnathodus* n. sp. A zone of Charles Collinson and others.[39]

Age of Rome Formation in central Kentucky

L. D. Harris has compared detailed surface mapping of the Rome Formation and Conasauga Group in northeastern Tennessee with deep well records from adjacent parts of Virginia and Kentucky. From this comparison he concludes that the Rome Formation, which is of Early Cambrian age in its outcrop areas, is probably of Middle Cambrian age in the subsurface of central Kentucky (Harris, p. B25–B29).

Paleokarst features on Knox Group surface

Continuing studies of the upper part of the Knox Group in the Sequatchie Valley of southeastern Tennessee have provided additional information on paleokarst features developed on the surface of the Knox Group before renewed deposition in Middle Ordovician time. Collapse breccias found by R. C. Milici, of the Tennessee Division of Geology, and Helmuth Wedow, of the U.S. Geological Survey, occur along the interface between the uppermost thick limestone of the Knox Group and overlying fine-grained dolomite about 400 feet below the post-Knox unconformity. Ancient channels or sinkholes on the unconformity, filled with basal Middle Ordovician sediments, exhibit a stratigraphic relief of more than 100 feet.

Mount Rogers Volcanic Group subdivided in Virginia

In the Blue Ridge province of southwestern Virginia, a stratigraphic sequence in the Mount Rogers Volcanic Group has been worked out by D. W. Rankin. Three principal units are recognized: a lower heterogeneous unit consisting of conglomerate, graywacke, mafic siltstone, and basalt; a middle unit consisting of rhyolite and latite flows; and an upper unit of maroon mudflow conglomerate, arkose, rhythmite, shale, and minor basaltic pillow lava. The upper unit with mudflow conglomerate at the top underlies the Chilhowee Group or Early Cambrian and Early Cambrian(?) age with apparent conformity. Because several of these units from the oldest to the youngest lie on older Precambrian granitic rocks, the Mount Rogers Group must have been deposited in an area of basement rocks with considerable topographic relief.

Subdivision of the Glenarm Series in Maryland

Recent work by D. L. Southwick in the difficult and complex metamorphic rocks of the Piedmont in Maryland has provided better information than previously available on the stratigraphy of the Glenarm Series. So far recognized are a provisional lower sequence containing schistose quartzite (Setters Formation), marble (Cockeysville Marble), a thick unit of pelitic schist (eastern facies of the Wissahickon Formation), and a unit of metamorphosed slump breccia and related pretectonically disrupted metasedimentary rocks, probably part of the Sykesville Formation of Hopson.[40] A supposedly upper sequence containing conglomerate, quartzite, and interbedded phyllite and micaceous quartzite (Peters Creek(?) Quartzite) and a thick section of garnet-muscovite schist (compare western facies of the Wissahickon Formation) appears to be separated from the lower sequence by a discontinuity that is probably an unconformity or a major fault.

[39] Charles Collinson, A. J. Scott, and C. B. Rexroad, 1962, Six charts showing biostratigraphic zones, and correlation based on conodonts from the Devonian and Mississippian rocks of the Upper Mississippi Valley: Illinois Geol. Survey Circ. 328, p. 870.

[40] C. A. Hopson, 1963, Large-scale submarine landslip deposits in the Glenarm Series, Maryland Piedmont: Geol. Soc. America Spec. Paper 73, p. 10–11.

Corals in the Marcellus Shale in Virginia

Corals from a limestone nodule in the Marcellus Shale near Christiansburg, Va., collected by J. T. Dutro, Jr., and R. B. Neuman, were identified as *Nalivkinella* sp. by W. A. Oliver, Jr. The Virginia species is closely related to, or identical with, a species from the Stony Hollow Member (Cooper, 1941) of the Marcellus in eastern Pennsylvania, and suggests a correlation of the Virginian unit with the Cherry Valley Limestone Member of the Marcellus in New York.

Graptolites in Martinsburg Shale in New Jersey

Graptolites from two outcrops of the Martinsburg Shale near Clinton, N.J., discovered by Harry Dodge during graduate work at Princeton, were re-collected by Dodge and R. B. Neuman and have been identified by W. B. N. Berry (University of California, Berkeley) as of Early and Middle Ordovician age. The shale appears to overlie the Middle Ordovician Jacksonburg Limestone which, in turn, lies above a Cambrian and Ordovician carbonate sequence. One explanation is that the Martinsburg in this area may contain exotic slump blocks comparable to those bordering the Taconic Mountains in the Hudson River Valley.

Structural history of Ordovician rocks in Pennsylvania and New Jersey

A statistical study of minor structures in the Jacksonburg Limestone, Martinsburg Shale, and related rocks, recorded during mapping in easternmost Pennsylvania and western New Jersey by A. A. Drake, Jr., provides good evidence that these rocks have been deformed at least twice. Plots of slaty cleave age show regional rotation around well-defined tectonic axes, and later-developed slip cleavage is conspicuous locally. The Paleozoic rocks in this area can best be interpreted as the normal limb of a large recumbent fold that has been refolded and faulted.

Gaps in eastern Pennsylvania not due to superposition

Geologic mapping of a classic area of wind and water gaps in the vicinity of Delaware Water Gap, eastern Pennsylvania, recently completed by J. B. Epstein, shows that most of the gaps are located where erosionally resistant rocks are cut by faults or are otherwise thinned. This evidence is opposed to interpretations that the major drainage lines were superposed from a former peneplain or coastal-plain cover.

Two ages of diabase dikes in South Carolina

Recent mapping by N. C. Koch has shown that the granites and gneisses of Greenville County, S. C., are cut by many northwest-trending diabase dikes probably of Triassic age. Another set of diabase dikes trends about N. 25° E. These dikes are clearly older and somewhat metamorphosed; they are probably of Paleozoic age.

GEOPHYSICAL STUDIES

Airborne magnetic and radiometric surveys in support of geologic mapping and structural investigations in the Blue Ridge and Piedmont provinces were carried out (1) in western New Jersey, (2) in an area of large gabbro bodies in the vicinity of Baltimore, Md., and (3) in areas of crystalline rocks in northeastern and southwestern Virginia. This work almost completes aeromagnetic coverage of a belt of varying width in the crystalline Appalachians extending from central Virginia to the Maine-New Brunswick border.

Crystalline rocks at two levels in Reading prong

Analyses of aeromagnetic and gravity data by R. W. Bromery indicate that the crystalline rocks at the west end of the Reading prong in southeastern Pennsylvania occur at two levels, one exposed at the ground surface and one at a deeper level approximately a mile below the surface. Rocks of contrasting physical properties are interpreted as separating these levels of crystalline rocks.

Structural trends in basement rocks mapped by aeromagnetometer

Depths recently calculated from contoured aeromagnetic maps have provided new information needed in preparing a contour map of the top of the Precambrian surface in the Appalachian region and in defining structural trends in the basement rocks. The results (Griscom and Zietz, 1–64) indicate that magnetic basement rocks lie at much shallower depths than predicted from stratigraphic and structural evidence in the Taconic region of southwestern Vermont, in Clearfield County, Pa., in southwestern Virginia, and in northwestern Georgia. Northeast trends of elongate magnetic anomalies in west-central Pennsylvania interpreted by M. E. Beck, Jr., and R. E. Mattrick indicate a small but consistent divergence of Precambrian and Paleozoic structural trends, the Precambrian axes having a more northerly orientation. A markedly linear magnetic gradient, traceable from near Wheeling, W. Va., to Venango County, Pa., coincides with a slight break in basement slope and may record the presence of a major basement fault.

Radiometric highs in North Carolina

Analysis of aeromagnetic and radiometric data previously obtained in the Concord area, North Carolina, reveals two radiometric highs within an aeromagnetic low. One of the radiometric highs is over an exposed granite pluton, but the other is over an area of metagabbro and metadiorite injected by abundant granitic material and cut by granite dikes. This granitic material is probably the cause of the high radioactivity level but is not sufficient to cause the negative aeromagnetic anomaly if the mafic rocks extend to any depth.

GEOCHEMICAL EXPLORATION

High Rock quadrangle, North Carolina

Results of analyses of samples of stream alluvium from the High Rock quadrangle, North Carolina, reported by A. A. Stromquist, A. M. White, and J. B. McHugh (p. C88–C91) indicated slight but significant enrichment of base metals in the western half of the quadrangle compatible with the pattern of mineralization as indicated by prospects and mines northwest, west, and southwest of the area.

GEOCHRONOLOGICAL STUDIES

Data on age of the slate belt, North Carolina

Two lead-alpha age determinations by T. W. Stern on zircon from felsic crystal-lithic tuff from the Carolina slate belt suggest an Ordovician age for these rocks studied by A. M. White and others (1–63). The two samples are from the southeastern part of the Albemarle quadrangle, North Carolina. The new data add further support to the concept that much of the southeastern Piedmont province is of Paleozoic rather than Precambrian age.

QUATERNARY GEOLOGY

Studies of surficial deposits in the Appalachian region during the year were done mainly in conjunction with geologic mapping in several widely separated areas. J. B. Epstein found that ice of the Wisconsin Glaciation crossed Kittatinny Mountain in the Stroudsburg area, Pennsylvania, and that a hitherto unreported proglacial lake, called Lake Sciota, formed between the Wisconsin terminal moraine and the mountain.

An exposure of peat and associated clay and sand, first described by Kerr in 1875, was restudied during geologic mapping of a part of the Piedmont near Morganton, N.C., by J. C. Reed, Jr. (4–64). Pollen assemblages studied by E. B. Leopold and Louise Weiler showed that this deposit, located in a former valley 100 feet below the Piedmont upland surface, is not glacial but probably represents an interglacial episode in Pleistocene time. The Piedmont surface is significantly older and therefore is probably older than Pleistocene.

Unconsolidated clay, sand, gravel, and boulders in the buried valley of the Susquehanna River in Luzerne and Lackawanna Counties, Pa., were studied by M. J. Bergin, J. F. Robertson, and L. M. McNey in connection with the problem of mine drainage in the northern anthracite field. Preliminary results show that these deposits lie on an irregular surface with as much as 100 feet of topographic relief. A main channel and several tributary channels of the ancient glaciated valley system can be identified.

EASTERN PLATEAUS

PENNSYLVANIA

Revision of Devonian-Mississippian boundary

The need for revision of the Devonian-Mississippian boundary in north-central Pennsylvania is suggested by continuing geologic investigations in Tioga County. Strata previously believed to be of Mississippian age are reported by G. W. Colton to be of Late Devonian age on the basis of a preliminary field examination of fossil plant material by J. M. Schopf. If this conclusion is substantiated by laboratory examination, the boundary between the two systems will be raised, thus increasing the thickness of rocks assigned to the Upper Devonian Series and sharply decreasing the thickness of the Mississippian System. The fossil plants and a closely related regionally extensive and distinctive thin conglomerate bed together may furnish the most easily recognized boundary between the two systems yet reported in the State.

KENTUCKY

Geologic mapping of State

A major undertaking to provide complete detailed geologic map coverage for the State of Kentucky was begun in the fall of 1960, in cooperation with the Kentucky Geological Survey. The maps are being published as 7½ minute quadrangles (scale 1:24,000 in the Geologic Quadrangle Map series). As of June 30, 1964, 91 quadrangles have been published, 29 are in press, 106 are completed and in review, and 92 are currently being mapped. Quadrangles published during fiscal year 1964 are given in the "List of Publications" (see Kentucky, geologic maps, in the "Index to Publications").

Upper Mississippian revised in Cumberland Mountains

The stratigraphy of the Lee Formation has been revised by K. G. Englund on the basis of studies in the Cumberland Mountains of southeastern Kentucky (p. B30–B38). The Lee, which grades into and laterally intertongues with the Pennington Formation of Mississippian age, is redefined to include seven mappable members, in ascending order: the Pinnacle Overlook, Chadwell, White Rocks Sandstone, Dark Ridge, Middlesboro, Hensley, and Bee Rock Sandstone Members. Subdivisions of the Lee are based on lithologic changes in a repetitious sequence of massive conglomeratic sandstone and nonresistant units of thin-bedded sandstone, siltstone, shale, coal, and underclay. Predominance of massive quartzose conglomeratic sandstone with intervening coal beds distinguishes the Lee from the shale and limestone sequence of the Pennington.

Devonian sequence revised

Biostratigraphic study of the pre-New Albany Devonian succession in Kentucky by W. A. Oliver, Jr., and J. T. Dutro, Jr., has demonstrated the widespread nature of both new and previously recognized faunal zones. Rocks of Schoharie age include in the Louisville area the lower part of Jeffersonville Limestone; and at Kentucky Lane, the Camden Chert. Possibly some rocks of Schoharie age occur at Lake Cumberland. Rocks of Onondaga age include the remainder of the Jeffersonville and unnamed units at Kentucky Lake and Lake Cumberland. A coral fauna of Onondaga age is found in the Boyle Formation at one locality in the Broadhead quadrangle, southwest of Berea in eastern Kentucky, but other rocks, previously reported to be of Onondaga age, are of Hamilton age. The Boyle Formation is largely Hamilton in age; the Pegram Limestone may be entirely Hamilton in age. Rocks of Hamilton age, though widespread elsewhere, are not known in western Kentucky.

Mississippian channel fill mapped

Detailed mapping of an extensive channel-fill sandstone of Late Mississippian age along the eastern edge of the western Kentucky coal basin by W. C. Swadley, E. G. Sable, and W. L. Peterson has confirmed earlier work by L. L. Ray and others.[41] The deposit was traced for about 18 miles across the Flaherty, Big Spring, and Constantine 7½-minute quadrangles, and eroded remnants were found to extend northeastward about 3 miles to the vicinity of Tip Top in the Fort Knox quadrangle. The recent mapping indicates that the sandstone forms part of the Morretown Formation of Late Mississippian age and fills a channel that was cut as much as 140 feet into the underlying Paoli and Ste. Genevieve Limestones. In the northernmost outcrops the channel deposit is medium-grained sandstone but grades southward to medium- to fine-grained sandstone and clay shale containing small amounts of sandy limestone.

Extensive sandstone bar mapped in Mississippian

A large body of sandstone of Mississippian age has been partly delineated in south-central Kentucky by C. H. Maxwell, R. O. Lewis, and R. E. Thaden, during geologic mapping in the Russell Springs, Montpelier, Dunnville, and Knifley (Maxwell, 1–64) quadrangles, Russell and Adair Counties. The sandstone body is elongate, having a length of about 18 miles, a maximum width of 6 miles, and a maximum thickness of at least 240 feet. Trend of the sandstone is northwestward parallel to limestone reefs in the Fort Payne Formation that lie southwest of the sandstone. Contemporaneous development of sandstone and reefs is suggested. The sandstone body possibly formed as a nearshore bar; the reefs grew farther offshore. The proximity of the sandstone and reef limestone may be of commercial importance. The reefs are oil reservoirs in Adair and Metcalf Counties, but little is known of the extent of the sandstone in the subsurface.

Cryptoexplosion feature mapped in Bluegrass region

A circular cryptoexplosion feature 3½ miles northeast of Versailles, Woodford County, has been mapped by D. F. B. Black (p. B9–B12). The previously unreported structure has a diameter of about 5,000 feet and consists of (1) a brecciated central dome, (2) a marginal depression partly bounded by normal faults, and (3) an outer semicircular anticline of low amplitude on the east margin. Similarity of the Versailles structure to structures of known and supposed meteorite-impact origin and the high degree of brecciation, otherwise rare in the region, may indicate a similar origin for the Versailles structure.

[41] L. L. Ray, A. P. Butler, Jr., and C. S. Denny, 1947, Relation of sand deposits at Tip Top, Kentucky, to the Meramec-Chester boundary: Kentucky Dept. Mines and Minerals, Geologic Div. Bull., ser. 8, no. 9, 16 p.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY

Rift-valley hypothesis for midcontinent gravity high

Geologic features in the Lake Superior region provide a basis for interpretation of a prominent gravimetric anomaly that extends for 800 miles southwestward from Lake Superior. According to W. S. White, the size and configuration of the midcontinent gravity high lead naturally to a hypothesis, among others, that it is a fossil rift valley filled with Keweenawan lavas and sediments. Geologic information from the Lake Superior region, where the rocks causing the gravity high emerge from beneath their Paleozoic cover, offers some support to the rift-valley hypothesis, and also presents some puzzles. Supporting facts and inferences are the following: (1) The Keweenawan rocks are depressed with respect to the older rocks on either side. (2) The lava-filled trough has faults at or close to its margins in many places. (3) In Michigan, the Keweenawan rocks thin away from Lake Superior at a rate that suggests no great difference between the ancient and present margins of the trough. (4) The Lake Superior basin is probably not a simple syncline, and may well have irregularities in the form of uplifted and depressed blocks such as typify the great rifts of the world. As an example, both geologic and geophysical evidence suggest that the large gravity low mapped by Thiel [42] under the Bayfield Peninsula in Wisconsin is more readily explained as an ancient positive area (or horst) over which the lavas are thin or absent than as an area of extradordinarily thick sedimentary cover. The presence of a horst of this sort would mean that the Duluth Gabbro and Keweenawan lavas of Minnesota lie in one trough (or graben), and the Keweenawan rocks in the vicinity of the Michigan-Wisconsin State line lie in another.

The following features complicate the rift interpretation. (1) Border faults that can be seen today are reverse faults rather than normal faults; they dip toward the axis of the trough opposite to the direction of dip for the reverse faults that some geologists have postulated as a cause of grabens. (2) Relatively uniform basinward thickening of stratigraphic units observed in Michigan suggests that the margin of the basin was a hinge zone rather than a fault zone. (3) Keweenawan sedimentary rocks only locally contain abundant pebbles of more ancient (pre-Keweenawan) rocks, such as would normally be eroded from the uplifted margins of a steep-walled rift valley.

[42] Edward Thiel, 1956, Correlation of gravity anomalies with the Keweenawan geology of Wisconsin and Minnesota: Geol. Soc. America Bull., v. 67, p. 1079–1100.

MICHIGAN

Geophysical-geological studies of Marquette iron district

Magnetometer surveying by K. L. Wier and geologic mapping by J. E. Gair (2–64) northeast of Palmer in the Marquette iron-bearing district have provided the following information: (1) A magnetite-bearing unit, 50 to 100 feet thick, is in the lower part of the Siamo Slate. The magnetic expression of this unit appears to be a dependable stratigraphic marker and has been used to determine structural details. The unit is strongly magnetic in several places where it is in contact with metadiabase, and although the magnetite content may be quite large, such occurrences are probably too small in volume to be of economic importance. (2) A previously unrecognized body of the Negaunee Iron-Formation extends east of a tabular body of metadiabase in secs. 17 and 20, T. 47 N., R. 26 W. (3) A "sill-like" intrusion of metadiabase cuts across sedimentary beds, indicating that such intrusive bodies may not be reliable stratigraphic markers, as previously supposed. (4) Faulting occurred both before and after intrusion of metadiabase masses.

Angular unconformity at base of Ajibik Quartzite

Mapping by C. E. Fritts along the north limb of the Marquette synclinorium near Negaunee, Mich., has shown that the much debated angular unconformity at the base of the Ajibik Quartzite is well displayed about a quarter mile to half a mile east of U.S. Highway 41, rather than adjacent to the highway. Typical Kona Dolomite exposed several miles east of Negaunee grades westward into a nearshore facies of at least three slate-quartzite units, the lowest of which formerly was mapped in part as Ajibik near U.S. Highway 41.

Age of mafic intrusives in Gogebic district

Restudy of the east end of the Gogebic iron-bearing district, Michigan, by W. C. Prinz has revealed that the mafic intrusives in the Ironwood Iron-Formation in the area east of Wakefield are metamorphosed and are thus not Keweenawan in age as most previous workers believed. This interpretation casts doubt on the generally accepted idea that the mafic dikes and sills that localize many of the ore deposits of the district are Keweenawan in age. This difference in geologic age of intrusion might have significant bearing on hypotheses of the origin of the ore deposits.

Aeromagnetic surveys in Gogebic district

Aeromagnetic surveys have been made over about 800 square miles in Gogebic and Ontonagon Counties, Mich., covering the east end of the Gogebic iron range and the area immediately east of the range. Interpretation to date by J. E. Case (1–64), W. C. Prinz, and R. G. Reeves indicates that aeromagnetic anomalies are as much as 12,000 gammas over magnetic Ironwood Iron-Formation. Anomalies over a unit of magnetic clastic rocks reach 4,000 gammas in amplitude. Anomalies over the gneissic basement rocks are discontinuous, and the values are comparatively low. Diabase dikes that trend northeastward yield negative anomalies.

Aeromagnetic survey of central Upper Peninsula

An aeromagnetic survey has been made of approximately 2,000 square miles in parts of Baraga, Marquette, Dickinson, Alger, and Schoolcraft Counties in the Upper Peninsula of Michigan. Aeromagnetic maps by J. R. Balsley and F. A. Petrafeso (1–64) show four distinctive patterns in which anomalies are: (1) well defined, narrow, parrallel, and of east and west trend; or (2) poorly defined but of the same direction; or (3) well defined, wider, and passing from southerly to southeasternly courses; or (4) mainly broad, partly of easterly trend, partly without trend.

Negaunee Moraine reinterpreted

The Negaunee Moraine, although marked locally by kame-and-kettle topography, is characterized generally by its relatively low elevation and low relief as revealed from investigations by Kenneth Segerstrom (p. C126–C129). Thus, this feature is not a typical moraine, in that it is not ridgelike. The relief of the moraine and its resemblance to a kame terrace are characteristic of other features which have been mapped as late Wisconsin moraines in the Upper Peninsula. Reappraisal of the area between the Green Bay and Keweenaw sublobes may alter drastically the concept of well-ordered, convex-northward moraines in this interlobate zone, as depicted in glacial maps of the region.

IOWA

Aeromagnetic survey

A preliminary geologic interpretation of the central and southwestern parts of a 15,000-square-mile aeromagnetic survey in Iowa was prepared by J. R. Henderson, Isidore Zietz, and W. S. White (1–63). A provisional geologic map shows the distribution of Precambrian rocks beneath a Paleozoic and Mesozoic cover, and the principal conclusions are in general agreement with results from other geophysical studies to the northeast and southwest. The major feature is a section of lavas of Keweenawan age, several miles thick, in a downward folded or faulted structure. Flanking the lava are basins filled mostly with sandstones of late Keweenawan age. Shallow to moderately deep basins are believed also to occur on the upper surface of the lava trough. Magnetic evidence suggests a northeast extension of the Thurman-Redfield structural zone. New exploratory drilling for oil and gas may be justified along this zone and its possible equivalent on the western margin of the lava.

WISCONSIN

Structural control of zinc and lead ore

Zinc and lead ore in the Dodgeville and Mineral Point areas has been mined from joint-controlled and pitch-and-flat deposits in flat-lying beds of limestone and dolomite of Ordovician age, according to J. W. Allingham (1–63). Structure contours on the geologic maps delineate large asymmetric anticlines and intervening broad shallow basins that contain a rhombic pattern of small cross folds.

ILLINOIS

Major structural trends may have originated in Precambrian

Aeromagnetic, gravimetric, and well-log data were examined by M. E. Beck, Jr., for interpretation of structure, lithology, and topographic configuration of the concealed basement complex underlying much of northeastern Illinois. A number of prominent structures, particularly the La Salle anticline and the Ashton arch, seem to be underlain by analogous basement features, which themselves may correspond to major crystalline lithologic units. On the basis of this correlation, alternative genetic relations between Precambrian and Paleozoic deformation are postulated. Sedimentary rocks may be draped over crystalline ridges and troughs, the trends of which reflect Precambrian tectonism. In view of the large scale of some of the features involved, however, Paleozoic renewal of deformation along Precambrian structural trends seems a more likely explanation.

MINNESOTA

Aeromagnetic survey in northern part of State

An aeromagnetic survey of 47,000 square miles of northern Minnesota shows the magnetic effects of known iron-formations and igneous rocks in northeastern Min-

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nesota and provides a basis for identifying similar rocks to the west in areas of unknown geology and thick glacial drift. According to G. D. Bath, strongly magnetic values are caused by iron-formations with dominant remanent magnetization along the direction of the bedding and by Keweenawan mafic rocks with dominant remanent magnetization along a geomagnetic field. In striking contrast, the pre-Keweenawan igneous rocks give a dominant induced magnetization that reaches a maximum average of only 0.0020 gauss total magnetization.

Interpretations for western areas indicate discontinuous belts of iron-formation of the Soudan type extending westward and southwestward completely across Minnesota. Anomalies adjacent to the iron-formation belts resemble those found over large batholiths in the eastern part of the State, and they are interpreted as the effects of large masses of igneous rock of silicic composition. The presence of these features suggests that the Keewatin basement province of Canada extends into Minnesota and across the area of the aeromagnetic survey.

INTERIOR HIGHLANDS AND EASTERN PLAINS

ARKANSAS

Deformation in west-central Arkansas

B. R. Haley reports that a well in the Greenwood quadrangle of west-central Arkansas cuts through a zone of normal faulting at a depth of about 10,580 feet. The displacement of beds in the subsurface is 1,100 feet, but no displacement is observed at the surface. He concludes that some of the faulting occurred during early and middle Atoka time and that southward thickening of the Atoka Formation toward the Ouachita geosyncline is due to both downwarping and normal faulting.

MISSOURI

Aeromagnetic interpretation of St. Francois Mountains lead district

Aeromagnetic anomalies of less than 200 gammas are associated with topographic relief of exposed Precambrian granitic and volcanic rocks of the St. Francois Mountains in Missouri, according to J. W. Allingham. Anomalies resulting from hills of coarsely crystalline granite range up to 100 gammas in amplitude, whereas anomalies over comparable hills of fine-grained rocks, such as granophyre or devitrified volcanic rock, range up to 200 gammas. Anomalies related to normal faults or shear zones in igneous rocks have amplitudes less than 100 gammas, and are observed best in profile. Analyses of compound anomalies yield the subsurface configuration of isolated roof pendants.

Analytical methods used by Allingham in this study of total-intensity aeromagnetic data intensify the low-amplitude anomalies associated with buried hills and ridges of resistant Precambrian granitic and volcanic rocks. The hills and ridges, by controlling Cambrian sedimentary structures, localized lead deposits in overlying carbonate strata.

The observed total-intensity aeromagnetic field was continued downward toward its source, vertical derivatives were calculated, and residual anomalies were separated by use of an electronic digital computer. Of these methods, continuation of the total-intensity aeromagnetic field downward to the level of the Precambrian surface yielded the best correlation with extensive mine workings in the lead district.

TEXAS

Uplift of Edwards Plateau dated as Quaternary

An incomplete analysis by V. L. Freeman, based on gravel deposits and geomorphic evidence, indicates that much of the uplift of the southwest flank of the Edwards Plateau of south Texas has occurred since deposition of the oldest gravel deposit. This gravel is believed to have been deposited at about the beginning of Pleistocene time. Since the early Pleistocene the Rio Grande has downcut through the Cretaceous limestones of the area, producing the presently entrenched meandering river. That the downcutting has been nearly continuous to the present day is shown by a scarcity of terraces and the narrowness of the canyon. Within the Rio Grande canyon more widening probably has been accomplished by rainwater solution of the limestone walls than by lateral erosion of the river.

New Paleozoic plant-fossil collection

A large suite of plant fossils collected by S. H. Mamay from upper Paleozoic sediments of North Texas includes the first plant fossils yet found in the Arroyo Formation of Leonard age, and several collections from new localities in the uppermost Pennsylvanian Harpersville Formation. The Arroyo collection contains elements characteristic of the Angara flora of Siberia, and other evidence in the new collections supports a close affinity between the Permian floras of Siberia and eastern Asia and those of the southwestern United States. The apparent abundance of well-preserved plants in the uppermost Pennsylvanian Harpersville Formation points up a strong possibility that the Pennsylvanian-

Permian boundary will eventually be pinpointed on paleobotonical evidence in an area where marine sediments are almost absent.

NEW MEXICO

Madera Limestone mapped

Over most of the Tajique quadrangle of central New Mexico the upper part of the Madera Limestone is composed of a rhythmic sequence of limestone, shale, and channel-fill deposits of arkose and sandstone, according to D. A. Myers. The limestone beds, which are in units as much as 100 feet thick, are fairly persistent from south to north, but wedge out into shale to the west. Locally, in the southeastern part of the quadrangle, the limestone beds have merged to form biostromelike deposits 200 feet or more in thickness. One rhythmic sequence of rocks, mapped as unit B by D. A. Myers, has been traced from south to north across the quadrangle. Fusulinid evidence indicates that the top of this unit is at about the Missouri-Virgil time line.

NORTHERN ROCKY MOUNTAINS AND PLAINS

NORTHEASTERN WASHINGTON

Deposits of breccia in the Klondike Mountain Formation (Oligocene) have been traced from the Bodie Mountain quadrangle, just south of the international boundary, into British Columbia by H. W. Little of the Geological Survey of Canada, and by R. C. Pearson. These are the first middle Tertiary rocks reported in this part of British Columbia. The locally derived breccias had previously been considered part of nearby Mesozoic and Paleozoic bedrock. To the southeast, limestone of late Middle or early Late Devonian age, found by A. B. Campbell in the Inchelium quadrangle, provides the first definite evidence of Devonian sedimentation in the area. The age of the limestone is based on the identification of conodonts by J. W. Huddle. These rocks may correlate with the probable Devonian limestone reported by Park and Cannon [43] near the Washington–British Columbia boundary.

The use of soil profiles in the correlation of glacial deposits has led to recognition by P. L. Weis and G. M. Richmond of five separate glacial advances in and near the Greenacres quadrangle close to Spokane. Only the ice of one advance, the next to the oldest, is known to have entered the Greenacres quadrangle; this ice advance blocked the Spokane River in two places above its mouth, forming glacial lakes, but did not reach the main surface of the Columbia Plateau. The edges of the other advances lay well north of Spokane Valley.

[43] C. F. Park, Jr., and R. S. Cannon, Jr., 1943, Geology and ore deposits of the Metaline quadrangle, Washington: U.S. Geol. Survey Prof. Paper 202, p. 22.

IDAHO

Purcell trench may be major fault zone

Rocks and structures on opposite sides of the north-trending Purcell trench differ markedly from each other, according to A. B. Griggs, suggesting that the trench is a major fault zone. This linear trench, 1 to 10 miles wide, is occupied by Coeur d'Alene Lake at the south and glacial outwash deposits to the north. The west wall of the trench is composed of high-grade metamorphic rocks, including sillimanite gneiss, of unknown age, cut by granitic intrusions. The east wall is made up of Precambrian Belt Series rocks that have been only slightly metamorphosed except where hornfelsed by granitic plutons. Opposite sides of the trench also are characterized by different structural trends, and the gross composition of the rocks before metamorphism differed, too.

Zones of progressive metamorphism related to temperature

Distinct episodes of synkinematic and postkinematic metamorphism are evident in textures and pseudomorphs of minerals in schist southwest of the St. Joe River, Idaho. Metamorphism increases markedly from the St. Joe River southward toward the Idaho batholith, where the following metamorphic zones have been mapped by Anna Hietanen: biotite, garnet, staurolite, kyanite-staurolite, kyanite, kyanite-sillimanite, and sillimanite. Pseudomorphs after large staurolite crystals in the northeastern part of the kyanite-staurolite zone consist of kyanite, muscovite, garnet, and small staurolite crystals, indicating that the second episode of metamorphism was at higher temperature. Each isograd moved 2 to 3 miles outward during the second metamorphism, which also indicates higher temperatures. The first metamorphic episode was contemporaneous with deformation and likely accompanied formation of magma at depth; greater temperatures accompanying the second episode probably record postkinematic intrusions at higher levels in the crust.

Dike swarm of possible middle Tertiary age reported

A dike swarm at least 3 miles wide trends east-northeast across the southeast corner of the Yellow

Pine quadrangle in west-central Idaho, and may be part of the northeast-trending Lowman-Middle Fork zone. According to B. F. Leonard, the swarm contains more than 180 mappable dikes, mostly of monzonite, rhyolite, and granite porphyry. Some dikes cut roof pendants, granodiorite and alaskite of the Idaho batholith, and Challis Volcanics (Eocene(?), Oligocene, and Miocene(?)). Granite porphyry dikes of this swarm resemble those in the adjacent Big Creek quadrangle, where one has a K–Ar age of 30 to 42 million years.

Volcanic rocks in the Yellow Pine quadrangle

Rocks in the eastern part of the Yellow Pine quadrangle previously identified as Casto Volcanics (Permian(?)) are assigned by B. F. Leonard to the Challis Volcanics (Eocene(?), Oligocene, and Miocene(?)). The tuffaceous lowest members of the volcanics contain sparse pebbles and cobbles of Idaho batholith (Cretaceous) rocks, confirming their postbatholithic age. The rocks are in part nonconformable on the batholith and in part faulted down against it.

Porphyroblastic gneiss near Idaho batholith

Porphyroblastic gneiss in the Blackbird Mountain quadrangle, west of Salmon, Idaho, has long been regarded as a border zone of the Idaho batholith. The gneiss, which is both underlain and overlain by quartzite of the Belt Series, is now thought by J. S. Vhay to be a product of dynamo-metamorphism. Elsewhere, intrusions of batholithic quartz monzonite into quartzite and argillite of the Belt Series have produced hornfels rather than gneiss.

Kinnikinic Quartzite near Clayton subdivided

Kinnikinic Quartzite near Clayton, Idaho, has been separated by K. B. Ketner into two units on the basis of stratigraphic, lithic, and metamorphic features. Ketner believes that the upper unit resembles Middle Ordovician strata in Utah; the lower, Cambrian and Precambrian quartzite in Utah. In the southern Lemhi Range, he believes that the Kinnikinic and part of the underlying Swauger Quartzite resemble Middle Ordovician strata of Utah.

Milligen Formation found to be thick and variable

The Milligen Formation of Early Mississippian age is thicker in the northern Lost River Range than previously estimated, and changes markedly in thickness within the Doublespring quadrangle, according to W. J. Mapel. The formation thins northeastward from 3,200 feet at McGowan Creek to 2,000 feet at Mill Creek, or 185 feet per mile in 6½ miles; it also thins southeastward to between 2,000 and 2,400 feet near Sheep Creek, or 100 to 140 feet per mile in 7 miles.

Pleistocene faulting in basin-ranges of east-central Idaho and adjacent Montana

The Lost River Range, Lemhi Range, and Beaverhead Mountains, basin-ranges in east-central Idaho and adjacent Montana, were broken in Pleistocene time by north-trending, dominantly right-lateral strike-slip faults, reports E. T. Ruppel (p. C14–C18). The faults, which control the striking zigzag pattern of these ranges, are in a zone about 50 miles wide that extends northward about 150 miles from Arco, Idaho, into the Big Hole Basin, Mont.

Occurrence of *Olenellus* in southeastern Idaho

The first known specimens of the Lower Cambrian index fossil *Olenellus* from southeastern Idaho have been found 170 feet below the top of the thick Brigham Quartzite in the Portneuf Range near Bancroft, reports S. S. Oriel. Previous assignment of the bulk of the Brigham to the Middle Cambrian is therefore erroneous.

High boulder gravel near Pocatello

Boulder gravel that mantles several square miles south of the Portneuf River, near Pocatello, and is more than 1,000 feet above present stream level, is interpreted by D. E. Trimble as a combined alluvial fan of Mink and Gibson Jack Creeks, graded to a temporary base level that may have been controlled by extinct Raft Lake of probable late Pleistocene age.

Snake River fault in southeastern Idaho

The Snake River fault, between the Swan Valley-Grand Valley graben and the Caribou Range in southeastern Idaho, is not a simple fault but a fault zone, report D. A. Jobin and M. L. Schroeder. In the Irwin quadrangle it consists of three closely spaced step faults, all thrown down to the northeast. In the Caribou Range, two thrust faults of early Tertiary age have been discovered by H. F. Albee and H. L. Cullins.

Thickening in Gallatin Limestone and Bighorn Dolomite inversely related

In the north-central part of the Snake River Range the Cambrian Gallatin Limestone thickens and the overlying Ordovician Bighorn Dolomite thins northwestward, according to D. A. Jobin, M. H. Staatz, and H. F. Albee. The Gallatin thickens from 150 feet to 435 feet within 8 miles; the Bighorn thins from 400 feet to 300 feet within the same distance, and to 80 feet at the northwestern end of the range.

WYOMING

Very pure dolomite reported from Snake River Range

In the Wells Formation (Pennsylvanian and Permian) of the Snake River Range in western Wyoming, H. L. Cullins and H. F. Albee have found a 10-foot-thick bed of pure dolomite of unknown but probable great extent. The dolomite is so pure that random samples may be used as dolomite standards in X-ray analysis.

Gravity low on north side of Wind River Basin

Bouguer anomalies range from a low of −230 milligals in the Wind River Basin to −190 milligals northward in the Owl Creek Range and to −160 milligals southward in parts of the Wind River Range and Granite Mountains. The major gravity low is asymmetrically located along the north side of the Wind River Basin, reflecting the position of the thickest sequence of sedimentary rocks just south of the Owl Creek Range, report J. E. Case and W. R. Keefer. Reverse faulting along the southern margin of the Granite Mountains, near Jeffrey City, is well expressed by a steepened gravity gradient of 6 milligals per mile above Precambrian rocks thrust over Mesozoic sedimentary rocks, as indicated by deep drill holes.

Silurian outlier found northwest of Sheridan

An outlier or tongue of Silurian rocks about 30 feet thick has been recognized by C. A. Sandberg in the Ash Creek oil field, northwest of Sheridan in northern Wyoming, and 45 miles south of the previously determined southern erosional limit of Silurian rocks. These newly recognized Silurian rocks may extend west to include outcrops between Tongue and Little Bighorn Canyons in the Bighorn Mountains.

Structure of Gros Ventre Mountains

W. R. Keefer (chapter D) concludes from studies in the southwestern part of the range that the Gros Ventre Mountains are an asymmetric anticlinal uplift, steep and faulted along the southwest margin. The range lies between structures typical of Laramide deformation (Late Cretaceous and early Tertiary) in central Wyoming and those of late Tertiary deformation in northwestern Wyoming. Keefer suggests that the Gros Ventre Mountains and adjacent Hoback Basin were formed during the Laramide and were modified by later movements.

Amsden Formation in Wyoming subdivided

The Amsden Formation in Wyoming has been subdivided into three units in a regional study by W. W. Mallory. The basal unit, the Darwin Sandstone Member, is clean and well sorted, making it an ideal reservoir for oil and gas; the middle unit is red shale of uniform thickness and composition; the upper unit is widespread cherty limestone. Mallory believes that the sand in the Darwin Sandstone Member and in the Tensleep Sandstone that overlies the Amsden was derived from an older sandstone, possibly of Ordovician age, in southern Canada.

Carbonate rocks in Park City Formation

Carbonate rocks in the Park City Formation of central Wyoming are believed by E. K. Maughan to have accumulated as skeletal detritus in offshore bars along the continental shelf and as lime mud in shoreward lagoons, comparable to similar deposits of the Bahama Islands. Suitable environment and abundant organisms account for the accumulation of oil in these rocks.

Lithologic study of Mowry Shale

Ten bentonite beds within the Mowry Shale have been used for basin-wide correlations as a result of detailed study by G. P. Eaton of six trenched sections along the west side of the Wind River Basin. An oft-suggested volcanic source to the west is affirmed by systematic variations in thickness and grainsize of the nonclay fraction. The lithology of the Mowry Shale and current-direction measurements in the underlying Muddy Sandstone Member of the Thermapolis Shale and the overlying Frontier Sandstone indicate that the sea floor sloped eastward in Mowry time and that the shoreline lay between long 109° and 110° W.

Continental Peak Formation dated

The Continental Peak Formation has been dated by means of fossil vertebrates found by H. D. Zeller and E. V. Stephens in the Oregon Buttes area. *Orohippus uintanus* (Marsh), found 65 feet below the top of Continental Peak, has been identified by G. E. Lewis, indicating that these rocks are a local facies of the upper part of the middle Eocene Bridger Formation.

Glacial chronology in Wind River Range revised

New work in the Wind River Mountains by G. M. Richmond (chapter D) and J. F. Murphy indicates that the youngest of three tills previously described as pre-Bull Lake in age instead represents an early stage of Bull Lake Glaciation. Another, as yet unnamed, till lies beneath the oldest of the pre-Bull Lake tills previously described. Terrace gravels correlative with each of these tills have been recognized along the Wind River. Recognition of a fourth important glacial advance during Pinedale Glaciation in the Pinedale area has resulted from G. M. Richmond's discovery of very blocky moraine in canyons along the margin of the Wind River Range at about the lower limit of the Pinedale ice cap.

Pleistocene limits of Yellowstone Lake interpreted

The Pleistocene extent of Yellowstone Lake is recorded in lacustrine sediments north of the lake recently examined by J. D. Love, in company with J. M. Good of the National Park Service. The sediments merge with similar strata in the now-abandoned Pelican Arm of Yellowstone Lake. Similar beds in Jackson Hole may represent a southern extension of the lake.

MONTANA

Major folded thrust northeast of Helena

A major folded thrust, named the Moors Mountain thrust, has been traced for 25 miles in and east of the Holter Lake quadrangle, northeast of Helena, Montana. The fault, which was discovered by W. B. Myers, nearly parallels bedding of overlying rocks and forms a northwest-plunging fold pair that shifts the fault trace 7 miles across regional strike, explaining the reversed-S pattern of Paleozoic units on the State geologic map. Southwest dips of the fault range from 20°to 55°; northeast dips in the reversed limb, from 30° to 45°. Greyson Shale (upper Precambrian) overlies rocks as young as Kootenai (Lower Cretaceous). The fault rises stratigraphically to the northwest. At the south edge of the quadrangle it places the basal part of the Greyson on the upper part of the Greyson strata and becomes hard to trace.

Overturned anticline north of Helena mapped

A large, eastwardly overturned, imbricately faulted anticline with a structural relief of about 10,000 feet has been mapped by R. G. Schmidt in the Wolf Creek area north of Helena. This fold is the north end of the Big Belt anticlinorium, in which superficial crustal shortening has been at least 6 miles.

Highland thrust south of Butte part of long zone

A long-known east-trending north-dipping thrust fault, in the Highland Mountains south of Butte, has been mapped in detail by H. W. Smedes and M. R. Klepper and named the Highland thrust. The thrust has moved Precambrian Belt Series rocks eastward over pre-Belt metamorphic rocks and apparently over the older Melrose thrust zone. They regard the Highland thrust as part of a 60-mile-long zone of similar thrusts that extends from the Pioneer Mountains to the Tobacco Root Mountains. The faults all trend east, dip north, and have moved Belt rocks eastward over younger rocks that had been folded along north to northwest-trending axes. These thrusts are interpreted by Smedes and Klepper as segments of a once-continuous thrust zone along which relative eastward displacement was at least 60 miles.

Magnetic anomalies found near Boulder batholith

Aeromagnetic studies near the Boulder batholith, by W. E. Davis, show large positive magnetic anomalies in places along the margins of the batholith, over Bull Mountain and the foothills of the southern part of the Elkhorn Mountains, and over the northern part of the Elkhorn Mountains.

Intensity of folding decreases eastward from Madison Range

The Tepee Creek quadrangle lies between overthrust Precambrian crystalline rocks of the Madison Range on the west and gentle open folds in younger sedimentary rocks in the Upper Gallatin Valley on the east. Intensity of folding within the quadrangle has been found by I. J. Witkind (1-64) to decrease eastward and northeastward; overturned folds and thrust faults in the west give way to broad open flexures that may form suitable oil traps in the north and east. These flexures are concealed in the northeastern part of the area by volcanic rocks erupted from vents to the east.

Folding thought to reflect laccoliths at depth

The Hughesville quadrangle lies along the north flank of the Little Belt Mountains laccolithic complex, which I. J. Witkind believes is reflected in domes and elongate anticlines in the exposed sedimentary rocks. A parent stock centered beneath Hughesville seems to have been the source of satellitic radial laccoliths.

Isotopic ages of glauconite beds in Belt Series

R. A. Gulbrandsen has recognized two principal glauconite horizons in Belt Series rocks (Precambrian) that have been correlated for a distance of 100 miles from Glacier Park south to Sun River, Mont. Additional K-Ar age determinations on the glauconite have verified the original determination of about 1,100 million years.[44]

More than twenty glauconite-bearing beds have been found by M. R. Mudge in Belt Series rocks in the Sun River Canyon area. Two samples collected from the Hoadley Formation, about 3,100 feet below the Flat-

[44] R. A. Gulbrandsen, S. S. Goldich, and H. H. Thomas, 1963, Glauconite from the Precambrian Belt Series, Montana: Science, v. 140, no. 3565, 390–391.

head Sandstone (Middle Cambrian), and analyzed by S. G. Walthal and C. E. Hedge, yielded Sr-Rb ages of 1020±50 m.y. and 1070±55 m.y. The glauconite-bearing beds have been traced for more than 25 miles and may prove useful in regional correlation.

Volcanic rocks of Livingston Group subdivided and dated

Deformed epiclastic volcanic rocks of the Livingston Group in the Maudlow quadrangle have been subdivided into eight map units by B. A. Skipp and interpreted as an allochthonous mass moved a few miles on low-angle faults. Textures and thicknesses suggest a nearby source for the volcanic rocks, though no contemporaneous intrusive masses are recognized in the map area. The volcanic rocks are assigned to the Upper Cretaceous on the basis of Lance pollen identified by R. H. Tschudy from 900 feet below the top of the 5,000-foot-thick sequence.

Stratigraphy of Livingston Group in Madison Range

The Livingston Group of the Madison Range has been divided into three members in the Cameron quadrangle by J. B. Hadley and E. J. Young. The lowest member, 300 to 500 feet thick, consists of interbedded chert-bearing and pyroxene-bearing sandstone, chert-pebble conglomerate, and plant-bearing volcanic siltstone. The middle member, about 900 feet thick, consists of coarse volcanic flow breccia, mostly polymict but partly homogeneous. The top member, at least 1,200 feet thick, consists of massive to crudely stratified volcanic cobble and boulder conglomerate. Many blocks of red felsite, several hundred feet long, in the middle unit may be intrusive. The area clearly lay near an eruptive center in Late Cretaceous time, but the center has not been found.

Significance of fossil fish in Maywood Formation

C. A. Sandberg and W. J. McMannis (p. C50–C54) report that a channel-fill deposit of the generally marine Maywood Formation in the Gallatin Range contains fish remains identified by D. H. Dunkle as *Bothriolepis* sp., permitting positive assignment of an early Late Devonian age and suggesting deposition in brackish or fresh water. Valleys previously inundated by an Early Devonian sea may have controlled and localized transgressions of the Late Devonian sea.

Volcanic vents discovered southeast of Bearpaw Mountains

Twelve volcanic vents have been found by B. C. Hearn, Jr., and C. P. Sabine in a faulted area near the Missouri River, southeast of the Bearpaw Mountains. The vents are 500 to 1,300 feet across and contain bedded pyroclastic rocks, intrusive breccias, olivine-rich igneous rocks, and slices of Fox Hills Sandstone and Hell Creek Formation (Upper Cretaceous), Fort Union Formation (Paleocene), and Wasatch Formation (lower Eocene) that have been dropped 1,000 to 4,500 feet. Vent activity may have begun in middle Eocene time, accompanying igneous activity in the Bearpaw Mountains. At least one vent was active late enough to incorporate rounded pebbles derived from igneous rocks of the Highwood Mountains or from a young (early late Eocene) series in the Bearpaw Mountains.

History of glacial Lake Missoula interpreted

Near Polsen, Mont., G. M. Richmond has found that sediments of glacial Lake Missoula are interbedded with each of three Bull Lake tills and with the oldest till of Pinedale age. Disconformities intervene between tills and lake sediments, indicating at least four separate stages of development of Lake Missoula. During the early stage of Pinedale Glaciation, rapid erosion of the lake's ice dam at Clark Fork produced the Spokane flood and the last major erosion of the channeled scablands.

Widespread unconformity separates Mississippian and Pennsylvanian strata

Preliminary interpretations of data gathered during work on the Mississippian and Pennsylvanian folios are providing a better understanding of ancient tectonic events in parts of the Rocky Mountain region. According to E. K. Maughan, an unconformity recognized in outcrops of the Heath Shale in central Montana can be traced widely in Montana and the Dakotas. In Maughan's opinion, rocks below the unconformity are Mississippian in age; rocks above it in the Heath begin a new cycle of deposition and are mostly Pennsylvanian in age rather than Mississippian as believed heretofore. In addition, Maughan's study suggests that Pennsylvanian rocks were widespread in Montana prior to northward beveling by pre-Permian erosion and subsequent complete removal in central to northern Montana prior to Jurassic deposition.

NORTH DAKOTA AND SOUTH DAKOTA

Synthesis of Quaternary geology of northern Great Plains

Several hundred man years of work on the Quaternary geology of the northern Great Plains have been synthesized in a cooperative project with the North Dakota and South Dakota Geological Surveys. The eastern parts of North Dakota and South Dakota were invaded by Nebraskan, Kansan, Illinoian and Wisconsin glaciers, report R. W. Lemke and R. M. Lindvall, of the U.S. Geological Survey, W. M. Laird, State Geologist of North Dakota, and M. J. Tipton, Assistant State Geologist of South Dakota. It now seems clear that the eastern parts of North and South Dakota were covered by ice during the Nebraskan, Kansan, Illinoian, and Wisconsin Glaciations. Western North Dakota and eastern Montana probably were glaciated by continental ice only during Wisconsin time. Six significant Wisconsin advances are recognized in the northern Great Plains; successive advances were, in general, more lobate in outline near their termini, their courses determined largely by high areas of bedrock.

Pre-Fall River folding in southern Black Hills

Surface and subsurface study of the Inyan Kara Group of Early Cretaceous age along the southern margin of the Black Hills by G. B. Gott (chapter D) indicates discordant relations between the Fall River Formation and the underlying Lakota Formation. This indicates that structural readjustments were in progress during the deposition of the Lakota. One domal structure, near Edgemont, S. Dak., showed 40 feet of closure on the top of the Morrison Formation, which underlies the Lakota, but no closure on the base of the overlying Fall River.

SOUTHERN ROCKY MOUNTAINS AND PLAINS

GEOLOGY OF PRECAMBRIAN ROCKS OF COLORADO

Plastic folding and cataclasis along Idaho Springs-Ralston shear zone

Detailed work on Precambrian rocks in the Southern Rocky Mountains continued to be focused on the Front Range, Colo., which has been the target of intensive study for several years. Studies by R. B. Taylor in the Blackhawk quadrangle near Central City have further clarified details of the complex structural history of the Preecambrian rocks in this area. Cataclasis resulting from the last of the 3 main periods of deformation has long been recognized, but Taylor has found that the east-northeast-trending Idaho Springs-Ralston shear zone, the largest structure formed during this period, began as a plastic monoclinal fold and progressed into a clearly defined zone of cataclasis by shearing along the steep limb. The closely compressed and sheared synclinal bend on the northwest side of the monocline is preserved as the prominent Coal Creek syncline.

Precambrian control of Laramide structures

Recent work by C. T. Wrucke in the Boulder quadrangle near the northeast end of the Front Range mineral belt has demonstrated close parallelism between faults, dikes, and veins of early Tertiary (Laramide) age and shear zones and mafic and granitic dikes of Precambrian age. This parallelism of structures of different ages in the mineral belt has been noted many times in the past, but the coincidence is particularly pronounced in the Boulder quadrangle.

Cordierite in Idaho Springs Formation

D. J. Gable, D. M. Sheridan, and C. T. Wrucke have found cordierite-bearing rocks in several different lithologic assemblages in the Precambrian Idaho Springs Formation in the central Front Range of Colorado. The cordierite-bearing rocks occur in part as discrete layers in metasedimentary sequences that crystallized during progressive regional metamorphism to a facies characterized by sillimanite, almandine, and microcline. The various layers commonly retained their compositional identities through metamorphism, and probably reflect original stratigraphic units. Other cordierite-bearing rocks are associated with igneous bodies, and were formed by more local contact metamorphism.

First occurrence of lepidolite in Front Range

Nearby in the southwestern part of the Squaw Pass quadrangle, D. M. Sheridan has found lepidolite in a zoned Precambrian pegmatite in association with cleavelandite, quartz, tourmaline, and muscovite. Although the small amount of lepidolite exposed does not necessarily indicate an economic deposit, the find is interesting mineralogically as lepidolite is not known to have been recognized previously in the Front Range.

Rocks of low metamorphic grade in Front Range

Whereas most of the metasedimentary rocks in the central Front Range are of high metamorphic grades and commonly contain sillimanite, a suite of rocks in the Cache la Poudre River area of the northeastern Front Range is of lower metamorphic grade. W. A. Braddock has determined that these rocks range from muscovite-chlorite-biotite phyllites through muscovite-chlorite-biotite-garnet-staurolite schists to muscovite-biotite-sillimanite schists and gneisses. These metasedimentary rocks have been intruded by plutons of Boulder Creek Granodiorite, of tonalite that resembles the Mount Olympus Granite, of Sherman Granite, and of biotite-muscovite granite.

Boulder Creek zircon yields highest isotopic ages reported in Front Range

T. W. Stern has completed isotopic lead-uranium measurements on zircon from 5 samples of rock collected by George Phair and David Gottfried from the Boulder Creek batholith area in the central Front Range; four of these samples are from typical Boulder Creek Granite, and one is from a younger granite dike that is regarded as a variant of the Silver Plume Granite. The measured Pb^{207}/Pb^{206} ages from the Boulder Creek batholith are all close to 1,730 million years. The Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206} ages are strongly discordant, as was anticipated from the range of Pb/alpha ages previously obtained on 25 different zircon samples from the same batholith. The Pb/alpha ages parallel the Pb^{206}/U^{238} ages, and both range down to a minimum of 1,050 million years. Zircon from the dike of probable Silver Plume Granite yielded Pb^{207}/Pb^{206} ages of 1,410 million years, roughly similar to the age of the Silver Plume Granite at its type locality, whereas Pb^{206}/U^{238} and Pb/alpha ages of the same rock are close to 1,050 million years. The age of 1,730 million years obtained by Pb^{207}/Pb^{206} ratio for Boulder Creek Granite is the highest so far reported for any rocks in the Front Range. Most other determinations have been made by isotopic methods on minerals more susceptible to modification by younger thermal episodes. The Pb^{207}/Pb^{206} age obtained on the dike of probable Silver Plume Granite indicates that rock of this type is Silver Plume in age and not a younger rock as was suggested by earlier Pb/alpha determinations.

Large folds noted in Black Canyon region

In western Colorado, W. R. Hansen has found that the Precambrian metamorphic rocks exposed in the Black Canyon of the Gunnison River have been folded into a series of north- to northeast-trending anticlines and synclines. Individual folds are 2 to 8 miles across, and have a structural relief of many thousands of feet. During the folding, the original rocks were transformed to gneisses, many of which exhibit the high metamorphic grade characterized by sillimanite.

STRATIGRAPHIC AND PALEONTOLOGIC STUDIES

Thinning of Triassic red beds along Park Range

Geologic mapping by W. J. Hail indicates that Triassic red beds along the east flank of the Park Range, Colo., thin southward from the Wyoming State line to the Lake Agnes quadrangle near Muddy Pass, and then gradually thicken farther southward toward Gore Pass. In the Barber Basin–Frantz Creek area in the Lake Agnes quadrangle, the red beds are only about 100 feet thick and are equivalent to only a part of Moenkopi Formation of Early and Middle(?) Triassic age. The thinning results both from (1) a wedging of the lower beds against the Precambrian rocks of an element of the ancestral Rockies positive area, and (2) erosion of strata equivalent to the Upper Triassic Chinle Formation prior to Jurassic sedimentation. In addition to the pattern of thinning in a north-south direction, thinning occurs eastward in the subsurface at an even higher rate. The Triassic rocks and also some of the overlying Jurassic rocks pinch out beneath the floor of North Park about 5 miles east of the foot of the Park Range. This overlap against Precambrian rocks of the old highland offers some potential for oil entrapment in sandstones of the Sundance or Entrada and Morrison Formations of Jurassic age.

Environment of deposition of Entrada Sandstone

After studying the stratigraphic relations of Jurassic and Upper Triassic sedimentary rocks in south-central Wyoming and northwest Colorado in detail, G. N. Pipiringos has interpreted a shallow-water marine environment of deposition for the Entrada Sandstone of Colorado and its counterpart, the Canyon Springs Sandstone Member of the Sundance Formation of Wyoming. At more than 100 localities, Pipiringos has found this sequence to consist dominantly of homogeneous, massive, crossbedded sandstone, but at 7 of the localities, the otherwise uniform lithology is interrupted by flat, thin beds of ripple-marked sandstone containing marine pelecypods, discrete lenses of gray oolite, and thin beds of red sandy siltstone. The fossils, oolites, and crossbedding suggest deposition in agitated shallow marine water. This interpretation is strengthened by lateral facies changes within the sequence. From the McCoy area on the west side of the Gore Range in Colorado, northeastward to near Kremmling, typical crossbedded Entrada Sandstone thins from 165 to 50 feet, and intertongues with and grades into gray-green shale and fine-grained sandstone containing marine pelecypods and microfossils. Northward from Kremmling, this Entrada equivalent grades into red sandy siltstone only 30 feet thick, then thickens and grades first into a sequence of marine shale, sandstone, and red siltstone beds, and then into the familiar massive crossbedded sandstone at Frantz Creek, 18 miles northwest of Kremmling, where it is again about 165 feet thick and comprises the Canyon Springs Member of the Sundance Formation.

Unconformity may help to subdivide Tertiary rocks

An angular unconformity has been mapped by D. M. Kinney within the sequence of lower Tertiary continental sedimentary rocks called Coalmont Formation in North Park and called Middle Park Formation in Middle Park, Colo. Porphyritic andesite pebbles in a greenish volcanic sandstone are characteristic of the unit below the unconformity. They are coarse and abundant in Middle Park, but decrease in size and abundance northward and are absent in northern North Park. In the unit above the unconformity, porphyry pebbles are rare in Middle Park and absent in North Park. In places, the two units are markedly discordant structurally, but in others they seem to be only subtly disconformable. If the unconformity can be traced over a sufficiently wide area, it will provide a convenient horizon for subdividing the stratigraphy of the lower Tertiary rocks, and should help greatly to clarify the geologic history of the North Park-Middle Park basin and adjacent areas.

Goose Egg Formation traced eastward into Wyoming

E. K. Maughan (p. B53–B60) has extended the Goose Egg Formation eastward into the Permian and Triassic red-bed sequence of southeastern Wyoming, and has restricted and redefined many of the names previously used in the area, giving them member status. The sediments that formed the Goose Egg Formation probably were deposited in a vast shallow lagoon or tidal flat that extended eastward from the deeper Phosphoria sea in central and western Wyoming.

Sharon Springs Member of Pierre Shale becomes younger southward along Front Range

Studies of the Pierre Shale along the east side of the Front Range, Colo., by W. A. Cobban and G. R. Scott have revealed that the Sharon Springs Member is a recognizable unit in the lower part of the Pierre near the Wyoming State line and near Pueblo, but not in the area between Loveland and Castle Rock, where shale in this part of the formation lacks the black, organic-rich aspect characteristic of the Sharon Springs. *Baculites asperiformis* is found in a sequence of beds about 40 feet thick in the upper part of the Sharon Springs Member at Pueblo. Near the Wyoming State line, however, this fossil is found through about 800 feet of sandy shale that lies above the Sharon Springs and represents an unnamed sandy unit in the Pierre Shale of southeastern Wyoming. These relations indicate that the Sharon Springs Member is not time equivalent in all occurrences, but is progressively younger southward.

Stratigraphy of Raton Formation in New Mexico

The Raton Formation of Cretaceous and Paleocene age is about 2,100 feet thick on the east flank of the Vermejo Park dome, Colfax County, N.M., as measured by C. L. Pillmore. The lower 1,000 feet of the formation is virtually barren of coal, and comprises 200 feet of coarse-grained to conglomeratic sandstone overlain by 800 feet of sandstone and minor interbedded claystone and siltstone. The upper 1,100 feet contains many layers of coal and consists mostly of claystone and siltstone containing interbeds of sandstone as much as 50 feet thick. Most of the coal beds are less than 5 feet thick, but the York Canyon coal bed, about 1,400 feet above the base of the formation, is as much as 11 feet thick. It is currently being developed. Mapping of the coal beds will appreciably increase the known coal reserves of the Raton field.

GEOLOGY OF VOLCANIC AND HYPABYSSAL INTRUSIVE ROCKS

Volcanic rocks in San Juan Mountains

Important stratigraphic and time correlations of volcanic rocks in the northern, western, and central San Juan Mountains, Colo., have resulted from work on five separate mapping projects there. Relations between cauldron complexes in the central and western San Juan Mountains have been established jointly by T. A. Steven and R. G. Luedke. The youngest rocks from the western source are ash-flow units in the Potosi Volcanic Group; these unconformably underlie the Mammoth Mountain Rhyolite from the central source. Dacitic lavas and breccias of the Huerto Formation, from another source area to the south, intertongue with both the western and central San Juan assemblages, and indicate that no significant break in volcanic activity intervened. Steven and Luedke traced two of the ash-flow units in the Potosi Volcanic Group 50 miles northward to the Gunnison River, where they are interbedded with other ash-flow formations. The Tertiary volcanic stratigraphy in the central San Juan Mountains, Colo., has been described by T. A. Steven and J. C. Ratté (2–64).

Ash-flow deposits in San Juan Mountains

J. C. Olson and D. C. Hedlund have mapped the ash-flow deposits on the north flank of the San Juan Mountains in an area of five 7½ minute quadrangles surrounding the Powderhorn district. These deposits are divisible into four formations, each of which may be divided into smaller units on the basis of degree of welding, devitrification, and other characteristics. The lowest ash-flow formation is found only in the vicinity of Lake Fork Canyon on the west side of the area and near the Gunnison River on the north, but remnants of the other three units are found over most of the area. The second formation from the top is a distinctive crystal-rich ash-flow tuff that forms a very useful marker unit over a large area, and is one of the two units traced northward from the central San Juan Mountains by Steven and Luedke.

Isotopic determinations indicate age of marker bed

W. R. Hansen has found the units that Olson and Hedlund described from the San Juan Mountains, Colo., as well as several other units, near the Black Canyon of the Gunnison, northwest of the Powderhorn district. Preliminary potassium and argon analyses by H. H. Thomas, R. F. Marvin, and Paul Elmore of a biotite concentrate separated by Hansen from the distinctive crystal-rich ash-flow tuff mapped farther east by Olson and Hedlund, and farther south by Steven and Luedke, indicate a tentative late Oligocene or early Miocene age. This isotopic determination is being checked by additional samples, and if valid will establish a point in time that wll be widely applicable to rocks in the San Juan region.

Ash-flows tuffs in Costilla Valley, N. Mex.

In a preliminary investigation of silicic volcanic rocks in Costilla Valley, Taos County, N. Mex., Paul Orkild and C. L. Pillmore have distinguished two sequences of ash-flow tuffs. The older sequence, of probable Pliocene age, is exposed along the east side of the valley in a downfaulted remnant of a former widespread sheet of volcanic rocks. It consists of about 1,000 feet of vitric nonwelded to densely welded ash-flow tuffs, overlain unconformably by a rhyolitic lava flow about 200 feet thick. A younger bed of ash-flow tuff floors Costilla Valley to a depth of about 200 feet. It post-dates faulting and erosion of the older sequence, and probably was erupted in late Pliocene or early Pleistocene time.

Age of tuffs from Middle Park and near Berthoud Pass

Sanidine from rhyolite tuffs collected by R. B. Taylor and Glen Izett in the Fraser and Kremmling basins in Middle Park, and from intrusive rhyolite porphyry collected by P. K. Theobald at the Red Mountain volcanic center near Berthoud Pass, have been analysed for potassium and argon by H. H. Thomas, R. F. Marvin, and Paul Elmore. All samples yielded a late Oligocene age. Geologic mapping by Izett in the Hot Sulphur Springs area in Middle Park has shown that the late Oligocene tuffs are part of a volcanic sequence that rests unconformably on the Middle Park Formation of Cretaceous and Paleocene age, and underlies tuffaceous intermontane basin-fill deposits. The basin-fill deposits contain a rich mammalian fauna that is classed as middle Miocene in age by G. E. Lewis. The volcanic sequence ranges from 0 to 2,000 feet in thickness and consists of a thin lower unit of alkalic olivine basalt flows and a much thicker upper unit of complexly interlayered rhyolitic to rhyodacitic tuff, tuff breccia, breccia, and welded tuff, and minor beds of conglomerate. The volcanic rocks are remnants of an extensive sheet that once covered uplands along the flanks of the Rabbit Ears Range north of Middle Park.

Welded tuff northeast of Salida, Colo.

Studies by M. G. Dings in the Cameron Mountain quadrangle, northeast of Salida, Colo., and the western edge of the Thirtynine Mile volcanic field, show that a widespread silicic welded tuff is older than the Antero Formation of DeVoto (1962) of Oligocene age. Previously, the tuff was thought to be contemporaneous with or younger than the Antero. The tuff extends into South Park to the north and northeast, and at one place or another it rests on an older Tertiary welded tuff, Paleozoic sedimentary rocks, and Precambrian rocks. Locally it is overlain by basalt flows younger than the Antero Formation.

Intrusive dike of welded tuff in Sawatch Range

Intrusive welded tuff forms a nearly vertical dike 30 to 50 feet wide and about 1¼ miles long near the crest of the Sawatch Range in the Mt. Harvard quadrangle, Colorado. According to M. R. Brock and Fred Barker, the rock consists of about equal parts glass shards, pumice fragments, and wallrock fragments; these materials were emplaced and welded at depths of at least 800 feet as indicated by the vertical range of exposure of the dike. The dike possibly may have been a feeder for an extrusive ash-flow tuff.

Silicic intrusives of West Elk Mountains cut Wasatch Formation

The West Elk Mountains in west-central Colorado are formed in part of silicic stocks, dikes, sills, and laccoliths that intrude the Wasatch Formation of Eocene age, as described by L. H. Godwin and D. L. Gaskill (P. C66–C68). The structure and composition of the igneous bodies are similar to those in comparable laccolithic intrusive centers on the Colorado Plateau to the west and southwest.

Walsen lamprophyre dike

R. B. Johnson (p. B69–B73) studied the Walsen dike near Walsenburg in south-central Colorado and found it to be composite, consisting of three dikes varying in composition from soda-minette to minette, each intruded at a different stage into a tension joint trending normal to the northerly strike of the sedimentary wallrocks.

QUATERNARY GEOLOGY

Map of bedrock geology and of Quaternary overburden in southeastern Nebraska

A map showing the bedrock geology and thickness of Quaternary overburden in an area of 8,400 square miles in southeastern Nebraska has been prepared by G. E. Prichard, of the U.S. Geological Survey, and E. C. Reed, V. H. Dreeszen, and R. R. Burchett, of the Nebraska Geological Survey. The map, which includes the Lincoln 1°×2° quadrangle and the southwest part of the Nebraska City quadrangle, is the first in a series of maps being prepared in cooperation with the Conservation and Survey Division of the University of Nebraska to provide statewide coverage at a scale of 1:250,000. The maps are intended for general purpose use; a knowledge of bedrock geology is fundamental for many and diverse purposes; the distribution and thickness of Quaternary overburden are important to the construction industry and as a reservoir for ground water.

Landslides in Golden area, Colorado

Studies prompted by the rapid urbanization of the Golden quadrangle, Colorado, have disclosed many landslides in the areas underlain by the Denver and Arapahoe Formations. Most of the landslides, according to Richard Van Horn, now appear to be stable, although some of those disturbed by human activity such as excavations or irrigation have again become active. Others will likely become active in the future if similarly disturbed.

Recent fault movement along Laramie Mountains

Recent fault movement in the Brush Creek area along the east flank of the Laramie Mountains in southeastern Wyoming has been documented by L. W. McGrew. The fault cuts several beds of alluvium, one of which contains snail shells that have been dated by Meyer Rubin, using radioactive-carbon techniques, as 9,500±400 years. A younger alluvium unit resting unconformably across the eroded trace of the fault also contains snail shells, dated by Rubin as 1,520±300 years old. The late movement bracketed between these ages offset the alluvial deposits at least 20 feet.

Pleistocene stream capture in South Platte drainage

A complex history of Pleistocene drainage changes along the South Platte River is being unraveled by P. E. Soister in the Platteville, Fort Lupton, and Hudson quadrangles north of Denver. Numerous remnants of deeply weathered gravelly alluvium capping hills and underlying Beebe Draw 3 to 10 miles east of the present South Platte River in this area are believed to represent channels of the South Platte River in pre-Nebraskan(?), Nebraskan, Kansan, and most of Illinoian time. A shift to the present course was accomplished in about latest Illinoian time by stream capture in the area between Denver and Brighton.

Ash beds south of Black Canyon, Colo.

In mapping the Pleistocene valley-fill deposits in Bostwick Park and Shinn Park valleys, south of the Black Canyon of the Gunnison, Colo., R. G. Dickinson has found three separate rhyolitic volcanic ash beds. The lower ash bed, as much as 4 inches thick, is at the base of the valley-fill section; the middle bed, as much as 3 feet thick, is about 35 feet above the first and overlies a moderately developed soil zone; the upper bed, as much as 8 inches thick, is about 125 feet above the middle bed and about 4 feet above a second strong soil zone. Each of the lower two ash beds contain phenocrysts of chevkinite, green ferroaugite, and white zircon, but refractive indices of the green ferroaugite and the surrounding glass shards in the two beds are different. The upper ash bed differs in mineralogy from the other two. The mineralogy of the middle ash bed is identical with that of the Pearlette Ash Member of the Sappa Formation of Kansan or Yarmouth age in Nebraska. The occurrence of tuff of this composition in the Bostwick Park area is the second to be reported near the Black Canyon of the Gunnison, and if the correlation with the Pearlette is valid, it is of great importance in the dating of Pleistocene events, as well as establishing further extension of this widespread ash unit.

GEOPHYSICAL INVESTIGATIONS

Aerial radioactivity survey of Denver area

Aerial radiological measurements by Peter Popenoe have shown that the natural gamma radioactivity level within the Denver area ranges from 300 to 1,500 counts per second. The highest radioactivity was found over alluvium derived from the crystalline rocks of the Front Range and occurring either as upland gravels or as recent alluvium along modern streams. The radioactivity of alluvium diminishes eastward along the South Platte River. High radioactivity was found also over arkosic sandstones and conglomerates of the upper part of the Dawson Arkose and in the Castle Rock Conglomerate both of which were derived from the crystalline rocks of the Front Range. Median levels of radioactivity were found over the Laramie, Arapahoe, and Denver Formations, the Pierre Shale, and over loess and some dune sand. Low levels of radioactivity are associated with the limestone and sandstone beds that crop out in the hogback ridges along the Front Range, and with dune sand and sandy alluvium along the South Platte River.

Regional gravity low in Colorado mineral belt

Geophysical investigations by J. E. Case in the headwater area of the Arkansas River have disclosed a large regional gravity low of 30 to 50 milligals that trends northeast across the Gore and Tenmile Ranges from Leadville to Breckenridge along the trend of the Colorado mineral belt. From Leadville, the same low extends southward diagnonally across the Arkansas Valley and along the Sawatch Range at least 10 miles and into the area underlain by the Twin Lakes pluton of Tertiary age. Scattered data farther south suggest that it may continue across the Mount Princeton batholith in the southern Sawatch Range. Gravity gradients along the flanks of the anomaly are steep, and probably reflect an intracrustal, relatively near-surface mass of lighter rock. The coincidence of the gravity low with an area containing many intrusive igneous bodies of early Tertiary age suggests that this buried mass of lighter rocks may be a batholitic body of regional proportions.

Gravity low in the San Juan volcanic field

A gravity survey made by D. E. Karig in and around the San Luis Valley, Colo., disclosed a gravity low over the Bonanza area in the northeastern part of the San Juan volcanic field. This anomaly is believed to reflect a caldera collapse structure related to volcanic eruptions during middle Tertiary time. Available geologic and gravity evidence suggests that the suspected caldera has an elliptical outline with axes of 8 and 10 miles, and is filled with about 8,000 feet of low-density material.

Gravity low associated with the Valles caldera, New Mexico

Gravity and aeromagnetic surveys by H. R. Joesting and L. E. Cordell in the Jemez and Nacimiento Mountains, New Mexico, show that a 35-milligal gravity low is associated with the Valles caldera. An extension of this low to the northeast probably reflects an earlier caldera now mostly obscured by the Valles caldera. The Valles anomaly closely resembles gravity anomalies over large volcanic calderas in Japan and the western United States, and by analogy with these, the Valles anomaly may be caused by a low-density mass more than 10,000 feet thick. The faulted western border of the Rio Grande trough can be traced beneath the Valles volcanic field, but it is difficult to separate effects of basement structure from those of near-surface volcanic rocks. Gravity and aeromagnetic data indicate segmentation of the Rio Grande trough and discontinuities of the fault boundaries of the trough, which are not evident from surface geologic mapping. A prominent northwest-trending regional magnetic anomaly which transects the Valles caldera indicates a major discontinuity in the Precambrian rocks, which is reflected in part by minor displacements in the Paleozoic rocks. The caldera thus apparently lies at the intersection of two major regional basement structures.

COLORADO PLATEAU

GEOPHYSICAL STUDIES

Magnetic and gravity patterns in and around Uncompahgre uplift

J. E. Case found that the 16,000 to 19,000 feet of structural relief on the Precambrian surface from the crest of the northwestern part of the Uncompahgre uplift, Colorado, southwestward to the deepest part of the Paradox Basin is reflected in a magnetic anomaly of about 300 gammas. Paradox evaporites and other Paleozoic sedimentary rock units wedge out, pinch out, or were eroded along the Uncompahgre front and therefore are in relatively sharp contact with relatively dense Precambrian quartz monzonite on the flank of the uplift. The quartz monzonite in turn is in contact with denser gneiss on the crest of the uplift. This juxtaposition of rock types of different density gives rise to a total gravity anomaly of 50 milligals or more. The combined geologic and magnetic data serve to outline in the same region unexposed bodies of quartz monzonite, many of which are concentrated in two belts.

GEOLOGICAL STUDIES

Regional study of Chinle Formation in northeastern Utah and northwestern Colorado

F. G. Poole and J. H. Stewart reported (chapter D) on a regional synthesis of information on the Chinle Formation (Late Triassic) and related sediments in the area extending from the Continental Divide west to the Uinta Mountains. They recognize a regional angular unconformity at the base of the Chinle throughout the area and at the top of the Chinle in northwestern Colorado. Six members are recognized, only one of which extends throughout the area.

Sonsela Sandstone Bed in Chinle Formation

Preliminary study of subsurface information indicates to J. D. Strobell that the Sonsela Sandstone Bed in the middle of the Petrified Forest Member of the Chinle Formation is an extensive well-defined stratigraphic unit that is readily identified in the subsurface of the western San Juan Basin, N. Mex., and northeastern Arizona. It is so prominent that it has commonly in the past been miscalled Shinarump Conglomerate, thus leading to the misidentification of the underlying beds as "Moenkopi" Formation. The Sonsela appears to be physically continuous with the Poleo Sandstone Member of the Chinle in New Mexico and and the Moss Back Member in Utah. In the central part of its basin of deposition, near the Four Corners, it becomes limy, and perhaps represents deposition in a lake to which the marginal sandy and conglomerate beds were graded.

Tonguing of Juana Lopez Member of Mancos Shale

Detailed sections of the Juana Lopez Member of the Mancos Shale, measured by C. H. Dane and E. R. Landis, indicate that the uppermost part of the Juana Lopez in the Chama Embayment of the San Juan Basin, N. Mex., tongues out northward and is not present in the vicinity of Pagosa Springs, Colo.

Coral distribution in Redwall Limestone in Arizona

W. J. Sando (p. C39–C42) has analyzed the coral distribution in the Redwall Limestone of northern Arizona and found that the Horseshoe Mesa Member, highest unit of the formation in Grand Canyon, has been removed by post-Redwall, pre-Pennsylvanian erosion in most of the area south of the canyon. The Redwall coral faunas suggest an age range from Kinderhook to Meramec and permit correlation of the formation with all but the lowermost part of the Madison Group and with post-Madison Mississippian strata.

Mancos Shale and Mesaverde Group west of Albuquerque

A strategically located stratigraphic section of part of the Mancos Shale and Mesaverde Group in the Rio Puerco Valley, west of Albuquerque, in Sandoval and Bernalillo Counties, N. Mex., was measured photogrammetrically by A. B. Olson, using a Kelsh plotter. The outcrops in T. 11 and 12 N., R. 2 W., are the southeasternmost in the general area where this part of the section is measurable and the nearest to the corresponding rocks exposed on the east side of the Rio Grande trough. Dips are low, the section extends across several miles of exposures, and the beds are broken by numerous faults.

Coral beds above Mancos Shale correlated

Fossils collected by R. G. Dickinson from the upper part of the Mancos Shale in the Cerro Summit area east of Montrose, Colo., were identified by W. A. Cobban as belonging to the *Didymoceras cheyennense* faunal zone of the Campanian Stage. This indicates that the coal-bearing beds immediately above the fossil zone correlated with the Fruitland Formation of the San Juan Basin to the south.

Restudy of Ojo Alamo Sandstone

A restudy of the type Ojo Alamo Sandstone in the San Juan Basin, N. Mex., by E. H. Baltz and S. R. Ash, of the Geological Survey, and R. Y. Anderson, of the University of New Mexico, indicates that the upper conglomeratic sandstone rests on a deeply channeled erosion surface cut in the medial dinosaur-bearing shale which is a persistent unit, rather than a lens as reported by C. M. Bauer.[45] The upper conglomeratic sandstone also intertongues with the Nacimiento Formation and contains a pollen assemblage identical with an assemblage from the beds of the Nacimiento that contain Puercan mammals. Thus, the upper part of Bauer's Ojo Alamo is Paleocene and rests unconformably on the middle part, which is Late, but not latest, Cretaceous. These facts indicate that the Ojo Alamo Sandstone should be redefined, and that concepts of the nature and stratigraphic position of the Cretaceous-Tertiary boundary in the San Juan Basin should be revised.

Artifacts and tree rings date alluviation and erosion

Continuing studies by M. E. Cooley of the sequence of alluviation and erosion in late Quaternary time in the central and southern parts of the Colorado Plateau

[45] C. M. Bauer, 1917, Stratigraphy of a part of the Chaco River Valley: U.S. Geol. Survey Prof. Paper 98–P, p. 275, 276.

indicate that during the past 1,000 years, periods of alluviation and of arroyo cutting can be compared with the centuries-long tree-ring chronologies of Schulman.[46] The chronology of the geologic deposits and sequence of events have been dated mainly from associated archaeological deposits, the ages of which were determined by the tree-ring dating technique. Comparison of the alluvial-erosional sequence with the tree-ring data indicates that alluviation occurred during periods of generally excessive tree growth—before A.D. 1100 and between about A.D. 1300 and 1850; whereas arroyo cutting occurred during periods of generally deficient tree-growth—between A.D. 1100 and 1300 and since 1850. The comparison also indicates that fluctuations of less than about 25 years duration in the tree-growth records are not recognizable in the geologic record.

Mineralogy of tuff beds in Green River Formation

Petrographic studies have been made by R. L. Griggs of the altered tuff beds in the Green River Formation in the southern Uinta Basin, Garfield and Rio Blanco Counties, Colo. Although none of the tuff beds contain distinctive diagnostic minerals, as does the Pearlette Ash Member of the Sappa Formation, that would permit widespread use and ready recognition, one of the beds was recognized as a multiple ash-fall unit; this characteristic, readily observable in the field, allows extensive use of the bed as a stratigraphic marker within much of the Piceance Creek Basin. Of geochemical interest is the observation that the altered tuff beds contain more abundant analcite than albite at the rim of the basin. Conversely, in the center of the basin, analcite is absent and the tuff beds have been replaced by albite and quartz. This difference in mineralogy probably reflects increased alkalinity toward the center of the basin.

1: 250,000-scale geologic map of Shiprock quadrangle

A new geologic map of the Shiprock quadrangle, New Mexico and Arizona (O'Sullivan and Beikman, 1–63), portrays the geology of an area in the heart of the Colorado Plateau covering 2° of longitude and 1° of latitude. The map consists of two sheets compiled on a scale of 1:250,000 from more than 20 sources. It is the first of 10 similar quadrangles that will, when completed, cover much of the Colorado Plateau.

Block diagram of the San Rafael Group in Utah

A new block diagram (Wright and Dickey, 1–63) shows the lithologic changes accompanying the gradual thickening of the San Rafael Group westward across the ancient platform of the present Colorado Plateau portion of Utah. Also shown are the abrupt changes in lithology and thickness farther west at the margin of the ancient miogeosyncline in the present transition area between the Colorado Plateau and the Basin and Range provinces.

Geologic map of area in and near Colorado National Monument

Published during the year was a map by S. W. Lohman (1–63) of an area south of Grand Junction, Colo., that includes the Colorado National Monument. An outgrowth of Lohman's study of the geology of the area was a request by the National Park Service that he guide the preparation of interpretive geologic diagrams, explanations, and pictures of some of the significant geologic features of the monument. These illustrations, prepared by John Stacy, scientific illustrator, are now on display in the monument.

BASIN AND RANGE REGION

STRATIGRAPHY AND STRUCTURAL GEOLOGY

NEVADA AND EASTERN CALIFORNIA

Stratigraphic correlations in White and Inyo Mountains

Working in Inyo County, Calif., and the contiguous part of Nye County, Nev., J. H. Stewart has revised previously accepted correlations of upper Precambrian and Lower Cambrian strata. The Reed Dolomite of the Inyo and White Mountains, which had previously been considered to be correlative with the Noonday Dolomite of the Death Valley-Spring Mountains region, is correlated instead with dolomite that develops by change of facies out of the upper part of the Stirling Quartzite of the same region. The Deep Spring Formation, which overlies the Reed Dolomite, and the Campito Formation, which in turn overlies the Deep Spring Formation, correlate with the lower and middle parts of the Wood Canyon Formation of the same region. Previously the Deep Spring Formation had been correlated by many geologists with the Johnnie Formation of the Death Valley-Spring Mountains region, and the Campito Formation had been correlated with the Stirling Quartzite.

Stratigraphic attenuation along plutonic contacts in White and Inyo Mountains

C. A. Nelson found that the White and Inyo Mountains contain several plutonic bodies, mainly quartz

[46] Edmund Shulman, 1956, Dendroclimatic changes in semi-arid America: Tucson, Ariz., Arizona Univ. Press.

monzonite, that appear satellitic to the plutons of the Sierra Nevada. In contrast to most of the Sierra Nevada, where host rocks are moderately to highly metamorphosed and their original nature is obscure, the rocks which the White-Inyo plutons intrude are only slightly metamorphosed and can readily be recognized. This feature has made possible detailed mapping of stratigraphic units which reveals that large-scale stratigraphic attenuation (in some places the strata have lost 85 percent of their thickness) is a common feature adjacent to regionally concordant plutonic contacts.

Historic faulting in western Nevada suggests regional strike-slip relations

D. R. Shawe believes that the map pattern and sense and direction of movement on certain faults in western Nevada, on which ground rupture has taken place in historic time, suggest an origin related to strike-slip faulting. Surficial ruptures resulting from fault movement associated with seven major earthquakes that have occurred during the past 60 years form a coherent arcuate linear zone (the Churchill arc) which can be thought of as resulting from a stress system acting at a single instant in geologic time. The Churchill arc transects several mountain ranges, suggesting that it is a structure of higher order than the individual mountain ranges. A transition from dip-slip normal faulting at the north end of the arc to dominantly right-lateral strike-slip faulting at the south end suggests a relation to the Walker Lane at the south end. The Walker Lane is a major northwesterly trending structural zone along which significant right-lateral strike-slip displacement is believed to have occurred.

A surface rupture that formed during one other historical earthquake in this part of western Nevada, in the Excelsior Mountains, is oriented northeasterly and is characterized by left-lateral strike-slip movement.

The strike-slip fault in the Excelsior Mountains and the Walker Lane, taken together, may be regarded as forming an active conjugate system, paralleled in California by the San Andreas-Garlock strike-slip fault pair, and throughout Nevada by transverse lineaments, some of which show evidence of strike-slip deformation. Altogether, these elements may reflect a stress system that affects much of the Basin and Range province.

Shawe suggests that the basin-ranges, exemplified by those along the Churchill arc, formed in the vicinity of large-scale strike-slip structures. Detailed orientation of ranges has been controlled by a generally north-south structural "grain" established prior to Cenozoic growth of the basin-ranges.

Structural bends parallel facies boundaries in western Nevada

Working in Esmeralda County, Nev., J. P. Albers (2-64) has concluded that the large horseshoe bends or oroclines marked by the Palmetto Mountains and other arcuate ranges are paralleled by the trends of at least three facies boundaries in Paleozoic and Mesozoic rocks. The facies boundaries and structure of pre-Cretaceous rocks show that the orocline marked by the Palmetto Mountains is dextrally coupled with an oroclinal bend of similar magnitude immediately to the west; the combination of the two oroclines gives the appearance in plan of a gigantic drag structure between the Sierra Nevada and Basin and Range structural units. At least three right-lateral strike-slip faults trending northwest and having displacements ranging from 8 to 26 miles are closely associated with but slightly younger than the oroclinal bends. The main deformation occurred during Middle or Late Jurassic time, and the total indicated right-lateral shift resulting from bending and faulting is 120 to 150 miles at the latitude of Tonopah, Nev. The Basin and Range block thus appears to be shifted southward in the right-lateral sense, relative to the Sierra Nevada.

Westward Mesozoic thrusting in north-central Nevada

R. E. Wallace and N. J. Silberling (p. C10-C13) have re-emphasized the presence of a westward-directed movement pattern of Mesozoic age in the tectonics of north-central Nevada, in a northeast-trending belt extending from the vicinity of Lovelock, Nev., to the Hot Springs Range northeast of Winnemucca, Nev. This direction of thrusting is opposed in sense to that of the Paleozoic thrusts, such as the Roberts Mountains thrust, and to other thrusts of Late Cretaceous and early Tertiary age in the central and eastern Great Basin. The chief evidence for the westward transport of the higher structural units is the geometry of the large-scale overturned folds. Although thrust faults are involved in this movement pattern, the direction of movement of the upper plate can seldom be determined from thrust relations alone.

Precambrian and Mesozoic rocks in Slate Range, Calif.

G. I. Smith, of the Geological Survey, and B. W. Troxell and C. H. Gray, of the California Division of Mines and Geology, have nearly completed reconnaissance mapping of the Slate Range, east of Searles Lake, Calif. This mapping has revealed large areas of previously unreported Precambrian(?) metaplutonic rocks and lower Mesozoic(?) metavolcanic rocks. A major fault zone trends diagonally northward through the range; it cuts rocks probably as young as late Mesozoic, but is overlapped by upper Cenozoic rocks. A large west-dipping low-angle fault crops out along the west edge; small grabens in lake gravels of early Wisconsin age are areally related to it and are thought to indicate that the major fault is a tensional feature that developed in late Pleistocene time.

Lower Cambrian fossils found in Nye County, Nev.

In mapping northern Nye County, Nev., Frank Kleinhampl has found fossils that demonstrate the presence of Lower Cambrian rocks in the Monitor and Toquima Ranges. This discovery will modify present ideas of the extent of the seaway that crossed in Early Cambrian time what is now Nevada.

Triassic rocks mapped in Inyo Mountains, Calif.

Ward C. Smith has found that Mesozoic strata crop out in a belt 25 miles long on the west slope of the southern Inyo Mountains, Calif. Two units are exposed. The lower, 2,500 feet thick, consists of marine limestone and shale of Early and Middle Triassic age; it rests unconformably on marine sedimentary rocks of Pennsylvanian to Permian age. Of the upper unit, strata about 7,000 feet thick are exposed, the top of the section being faulted away. Continental sedimentary and volcanic rocks make up this unit, which is unfossiliferous. These units were strongly deformed, evidently prior to the intrusion of batholithic granite masses of Mesozoic age. The Lower and Middle Triassic section is one of the most complete in this region.

Paleozoic plutonic rocks found in Pershing County, Nev.

D. B. Tatlock, mapping in Pershing County, Nev., has found two leucogranite plutons, one at the south end of the East Range and another, smaller one near the north end of the Stillwater Range, that are equivalent to upper Paleozoic leucogranite in the Humboldt Range. These are the only Paleozoic plutonic rocks thus far found in western Nevada.

WESTERN ARIZONA AND SOUTHEASTERN CALIFORNIA

Metamorphic rocks of Riverside Mountains, Calif.

Detailed mapping of the Riverside Mountains, Calif., by Warren Hamilton (1–64) shows that they consist of a very large recumbent isoclinal syncline of Paleozoic and lower Mesozoic(?) rocks enclosed between middle(?) Precambrian gneiss and migmatite. The Paleozoic and Mesozoic(?) rocks are pervasively deformed by bedding-plane shearing, thrust faulting, and isoclinal folding, and bedded and plutonic rocks are tectonically intercalated. Basement rocks of the lower (upright) limb are but little sheared and recrystallized, whereas basement rocks of the upper (inverted) limb are pervasively crushed; enclosed bedded rocks are metamorphosed to about the same degree as the retrograde metamorphism of the upper limb. Similar relations exist in the structurally similar Big Maria Mountains to the south. This indicates that the cause of the regional metamorphism is probably heat generated by the extreme deformation rather than heat conducted upwards into the crust.

Upper Cretaceous or lower Tertiary megabreccias derived from pre-Cretaceous rocks have been broken by gravity thrust faults and by left-lateral strike-slip faults striking north-northeastward.

Cyclic sedimentation of Cambrian rocks of Death Valley

A. R. Palmer has found, in a study of the stratigraphy of the Carrara Formation in the Death Valley region, California, that it includes part or all of four transgressive-regressive sedimentary cycles. Each cycle is terminated by a limestone unit and these limestones intertongue to the southeast with siltstones and shales. The lowest cycle, which begins with the underlying Zabriskie Quartzite, is entirely Early Cambrian. The second cycle includes Lower Cambrian shales and siltstones at its base and Middle Cambrian limestone at its top. The two upper cycles include early Middle Cambrian beds.

Mojave block north of San Andreas fault forms part of Mesozoic batholith

Geologic mapping of the pre-Tertiary crystalline rocks in the central and southern Mojave Desert and San Bernardino Mountains, Calif., by T. W. Dibblee, Jr., shows that the Mojave block north of the San Andreas fault is in effect part of a Mesozoic batholith of quartz monzonite that here contains pendant remnants of Precambrian(?) gneiss overlaid unconformably by Paleozoic metasedimentary rocks. The quartz monzonite was emplaced in at least two major waves, separated by the emplacement of masses and dikes of andesitic porphyry. Deposits of iron ore are associated with intrusives of the first wave. In the San Bernardino Mountains the San Andreas fault splits into several branches, and displacements on all are right lateral, but only on the north, major (Mill Creek) branch is displacement of major magnitude, measurable in at least tens of miles. This is indicated by the abrupt termination caused by this branch, of the Mojave block rocks

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mentioned, in which the gneiss dips regionally northwest. The adjacent southwest block is composed almost entirely of Precambrian (?) gneiss, schist, and mylonite, with a regional southward dip.

Oldest rocks in Arizona exposed in a plunging diapiric anticline

P. M. Blacet reports that the oldest rocks so far recognized in Arizona, the pre-Yavapai gneiss of Turkey Creek, southeast of Prescott, Ariz., are exposed in the core of a northeast-plunging diapiric anticline. Both the gneiss and the overlying Yavapai Series are cut out by intrusions of porphyritic granodiorite south of Battle Flat, thus limiting the exposed area of pre-Yavapai basement to about 10 square miles.

Stratigraphy revised in southwestern Arizona

L. A. Heindl and N. E. McClymonds (p. C43–C49), working in the Papago Indian Reservation of southwestern Arizona, have tentatively reclassified a well-known clastic unit, long correlated with the Troy Quartzite, of younger Precambrian age, as Bolsa(?) Quartzite, of Cambrian age. In the Vekol, Slate, and Waterman Mountains, the unit in question contains fragments of fossils, is conformable with the overlying Abrigo Formation, and rests unconformably either on rocks of the Apache Group or on Precambrian granite.

EASTERN NEVADA AND UTAH

Miocene and Oligocene fossils found in Humboldt Formation of eastern Nevada

J. F. Smith and K. B. Ketner suggest on the basis of field studies in the Dixie Flats-Huntington Creek area south of Elko, Nev., a revision of the age of the Humboldt Formation, formerly thought to be of Miocene and Pliocene(?) age. J. A. Wolfe has identified plant fossils of probable Oligocene age from the lower part of the Humboldt, and G. E. Lewis has identified late Miocene vertebrate fossils from the upper part.

Faulting in Confusion Range, Utah, dated

In the Confusion Range, in Millard County, Utah, R. K. Hose has found evidence that high-angle dip-slip faults, of irregular trend, with displacements of as much as 2 miles, were formed in late Mesozoic to pre-middle Tertiary time. These faults are locally overlapped by equivalents of the Needles Range(?) Formation of Mackin (1960) of late Oligocene to early Miocene age. Probably many, if not most, of the high-angle faults of the northern Confusion Range (including the Conger Range), whose relations to Tertiary units cannot be determined, were also formed during late Mesozoic to pre-middle Tertiary time.

Corals suggest correlation of Pilot Shale in Utah

Study of corals by Helen Duncan from the upper part of the Pilot Shale in the Confusion Range, Utah, and in the Pahranagat Range, Nev., resulted in the identification of two characteristic Carboniferous solitary rugose genera (*Permia* and *Rhopalolasma*) in association with the tabulate genus *Vaughania*, which is the guide fossil for the oldest Carboniferous faunal zone of Great Britain. The Pilot species of *Permia* is closely related to, if not identical with, the Louisiana Limestone coral previously identified as *Neozaphrentis parasitica* (Worthen). In the Confusion Range, the corals occur in a diversified assemblage, including productoid brachiopods and trilobites of early Carboniferous aspect, that bears a great deal of similarity to the fauna of the Louisiana Limestone of Missouri. An Early Mississippian assignment for the controversial Louisiana Limestone is therefore supported by several critical groups of larger invertebrates.

Tear fault inferred in East Tintic Mountains, Utah

H. T. Morris and W. M. Shepard (p. C19–C21) have found evidence for a concealed tear fault of large displacement in the central East Tintic Mountains, Utah. This fault, of probable east-northeasterly trend, is believed to terminate on the south of the Oquirrh-East Tintic system of folds and the East Tintic thrust. This inferred termination is beneath the lava cover of the central part of the East Tintic Mountains. A fault that is the possible continuation of the inferred tear crops out in the southern part of West Mountain, 15 miles northeast of the central East Tintic Mountains. This fault has been previously regarded as a thrust in which the upper plate moved southward with respect to the lower plate, but the structural style of the block northwest of this fault, as well as its outcrop pattern, are more nearly consonant with the interpretation offered here.

Similar late Paleozoic deposition in Nevada and Idaho suggests extension of Antler orogenic belt

R. J. Roberts and M. R. Thomasson (2–64) have compared the late Paleozoic depositional history of northern Nevada and central Idaho and have found many points of resemblance, leading them to infer an extension of the Antler orogenic belt into Idaho. The major thrust thus far known is post-early Permian, but they infer earlier major thrusts.

Imbricate thrust sheets in Oquirrh Mountains, Utah

R. J. Roberts and E. W. Tooker, mapping in the Oquirrh Mountains of Utah, report that a synthesis of stratigraphic and structural data from the Oquirrh Mountains and reinterpretation of data from some of the surrounding ranges indicate that the rocks in the Oquirrh Mountains are involved in a series of imbricate thrust sheets in which the strata have been telescoped. Some thrusts, such as the North Oquirrh thrust, separate strata of different sedimentary facies; the great difference in facies is believed to indicate that the displacements on such thrusts may amount to tens of miles. Other thrusts, such as the Midas thrust, separate strata of the same facies; they are mappable because the structural style of the upper and lower plates is different. The use of this criterion to distinguish plates separated by thrusts is relatively new in the eastern part of the Basin and Range province. The ore deposits at Bingham, Utah, occur in overturned, folded, faulted, and brecciated rocks, and are spatially associated with Tertiary intrusive rocks in the upper plate of the Midas thrust fault.

Major middle Tertiary or younger faulting suspected in Ruby Mountains, Nev.

Geologic mapping in the Jiggs quadrangle, Nevada, by C. R. Willden, has resulted in recognition of a klippe of a major thrust plate resting on the Harrison Pass quartz monzonite stock. A sample of this intrusive body collected by R. R. Coats has yielded a K–Ar age of 35 million years and a Pb-alpha age of 40 million years. If the dating of additional samples from this intrusive body, now in progress, confirms these dates as the actual age of the stock, then middle Tertiary or younger thrusting can be demonstrated in the Ruby Mountains.

Late Tertiary low-angle fault in Juab County, Utah

In western Juab County, Utah, near the Spor Mountain beryllium deposits, D. R. Shawe (p. B13–B15) has found a low-angle fault on which Cambrian carbonate sedimentary rocks have moved at least 1 mile over volcanic rocks of probable Miocene and Pliocene age. It is the youngest low-angle fault of this magnitude now known in the region. A tuff underlying the fault may be correlative with the tuff that contains large beryllium deposits at Spor Mountain, and therefore this fault, or others like it, may in places conceal additional beryllium deposits.

Movement along thrust fault in eastern Nevada

Harald Drewes reports (p. B20–B24) subsequent movement in diverse directions on an earlier thrust fault in the Schell Creek Range near Ely, Nev. These movements reflect first normal faulting, then low-angle gravity sliding, and finally renewed normal faulting, according to his interpretation.

Thrusting in Park City district, Utah

Mapping by C. S. Bromfield on the east side of the Park City mining district, in Wasatch and Summit Counties, Utah, shows that the Eocene(?) and Oligocene(?) volcanic rocks which flank the west side of the north-plunging Park City anticline were deposited on a surface of considerable relief and rest on beds ranging in age from the Pennsylvanian Weber Quartzite to the Triassic Thaynes Formation. The major movement on the Frog Valley thrust fault which cuts the sedimentary rocks along the east side of the anticline apparently antedates the volcanic rocks.

Lower Paleozoic rocks faulted over Tertiary deposits in Snake Range, Nev.

D. H. Whitebread has found several small areas on the east side of the southern Snake Range, Nev., where large masses consisting of brecciated rocks of Cambrian and Ordovician age are faulted over Tertiary gravels. The fault blocks are probably gravity slides from the higher areas to the west. Although the rocks within the upper plate are extremely broken, the individual units remained virtually intact, as the several formations in the upper plate remain as mappable units.

Offset of Egan Range, Nev., ascribed to faulting

Geologic mapping by A. L. Brokaw and P. J. Barosh in the Giroux Wash area of the Ely and Reipetown quadrangles near Ely, Nev., indicates that the abrupt offset of the Egan Range, between the south end of Radar Ridge and the north end of Rib Hill, may be due in part to a set of east-northeast-trending transverse faults. The rocks on Radar Ridge are tightly folded into a north-trending unbroken syncline, strongly overturned to the west. To the southeast for about 3 miles, only the east limb of the fold remains and this has been broken by a succession of high- and low-angle transverse faults having a cumulative offset to the east of more than a mile. South of Rib Hill, the syncline continues unbroken for more than 2 miles.

The intrusive rocks and related ore deposits are localized on the projection of the transverse fault zone, but the relation is obscured because of later north-trending normal faulting.

EASTERN ARIZONA, NEW MEXICO, AND WESTERN TEXAS

"Down-structure" method of tectonic analysis

P. B. King (p. B1–B8) has applied the "down-structure" method of tectonic analysis to steeply plunging complex structures in the Garden Springs area of the Marathon Basin of west Texas. When the map is oriented so that the geologist views it in the direction of plunge, the outcrop pattern becomes a structure section, but in a near-horizontal plane rather than the vertical plane of conventional structure sections. By this method of analysis it can be shown that the Garden Springs area contains what was originally a low-angle thrust fault that was subsequently steeply folded.

Paleozoic section studied in Whetstone Mountains, Ariz.

S. C. Creasey has found in the Whetstone Mountains the most complete and relatively undisturbed section of Paleozoic rocks in southeastern Arizona. From top to bottom the section consists of the Rainvalley Formation, Concha Limestone, Scherrer Formation, Epitaph Dolomite, Colino Limestone, Abrigo Limestone, and Bolsa Quartzite. The span of time is from Permian to Cambrian, but representatives of the Silurian and Ordovician are missing. Because the rocks are well exposed, the geologic structures are simple, and the Paleozoic section is so complete that the Whetstone Mountains will serve as a "reference range" for the Paleozoic stratigraphy of southeastern Arizona.

Percha Shale younger than Sly Gap Formation in New Mexico

Correlations and ranges of invertebrate fossils in Devonian rocks in New Mexico have been considerably strengthened as a result of fieldwork by G. A. Cooper, U.S. National Museum, and J. T. Dutro, Jr., of the Geological Survey. A major conclusion is that the Percha Shale of western New Mexico is entirely younger than the Sly Gap Formation of Stevenson (1941) in the southeastern and south-central parts of the State. It also appears that several close similarities to the Devonian sequence of western Canada can be documented.

Limestone rafted by volcanic flows in Arizona

In the Huachuca Mountains, Canelo Hills, and Santa Rita Mountains of southeastern Arizona, Harald Drewes, Philip Hayes, Robert Raup, and Frank Simons have found thousands of feet of rhyolitic tuffs, flows, and associated sedimentary rocks of Triassic or Jurassic age, in which exotic blocks of Paleozoic limestone, as much as half a mile in length, are a common feature. While some of these blocks are apparently ancient landslides, others seem to have been rafted into place by thick, viscous flows. Presumably these remarkable features result from the disruption of the roof of shallow laccolithic intrusions.

Quartz-vein mineralization in Santa Rita Mountains, Ariz.

In the Mount Wrightson quadrangle, Santa Cruz County, Ariz., Harald Drewes has studied a system of quartz veins that carry lead, silver, and zinc, and that were emplaced, probably in Miocene time, in a system of fractures that fan out like the leaves of an opened book standing on end, and that lie athwart the major north-northwest-trending Mesozoic structures.

Helmet Peak anticline of Pima district, Arizona

In the Pima copper district, Arizona, large-scale mapping by J. R. Cooper substantiates that the Helmet Peak anticline is a diapir with its roots in the east-trending thrust zone of Laramide age that is mineralized at the San Xavier mine, west of the root zone of the diapir. The plunge of the fold axis and the dip of the thrust zone are to the south, having been much steepened by the late southward tilting of this part of the district. Due to the flowage of the mobile core of the diapir, Permian rocks were driven upward three-quarters of a mile in an upright isoclinal anticline less than 1,000 feet wide that pierces Mesozoic red beds and arkoses normal to their trend.

CENOZOIC VOLCANISM

Shape of Three Peak intrusion, Utah

H. R. Blank, Jr., and J. H. Mackin report that an analysis of the magnetic anomaly produced by the Three Peak intrusion, the most easterly of the three bodies of quartz monzonite porphyry in the Iron Spring district, Iron County, Utah, shows that the intrusion must have the form of a thick plate, rather than a stock or plug. Using an effective susceptibility value of 6×10^{-3} centimeters per gram per second obtained from a ground magnetometer profile, the best fit with the observed amplitude and shape of the anomaly is obtained with a model slab about 3,000 feet in thickness. The improved precision for the shape may have important economic consequences.

Thick Tertiary volcanic sequence in Cady Mountains, Ariz.

Mapping in the Cady Mountains of the central Mojave Desert by T. W. Dibblee, Jr., and A. H. Bassett, reveals that the Mesozoic quartz monzonite platform is overlain by volcanic piles of Tertiary andesitic and basaltic rocks that accumulated to thicknesses of many thousands of feet around several vents. The volcanic sequence contains many vein deposits of manganese ore, fluorite, barite, travertine, agate, and jasper. It is overlain by a Miocene sedimentary sequence that contains lacustrine strata including deposits of celestite, lithium clay, and clinoptilolite tuff. Extensive accumulations of Pliocene and Pleistocene fanglomerate complete the sequence.

Volcanic sequence subdivided near Beatty, Nev.

In the general vicinity of Beatty and Goldfield, Nev., D. C. Noble, R. E. Anderson, E. B. Ekren, and J. T. O'Connor (4–64) have mapped a sequence of rhyolitic ash-flow and air-fall tuffs. These tuffs (Noble and others, 4–64) are called the Thirsty Canyon Tuff, and have been recognized in five formal members: the Spearhead, Trail Ridge, Dry Lake, Gold Flat, and Labyrinth Canyon Members, and an unnamed upper member. Each member was deposited within a short interval of time, and cooled generally as a single unit. The several members are soda rhyolites and pantellerites, and apparently are comagmatic. Phenocrysts include soda-rich sanidine, pigeonite, green clinopyroxene, fayalite, brown amphibole, and zircon. Quartz is rare. There is significant lateral and vertical variation in phenocryst, lithic-fragment, and pumice content within the individual members, which can also be distinguished one from another in general appearance and petrography.

Zonal features of ash-flow sheet studied

P. W. Lipman and R. L. Christiansen (p. B74–B78) have studied variations in chemical composition within an ash-flow sheet in the Piapi Canyon Formation in southern Nevada. They found that (1) the unwelded vitric tuff at the edges of the sheet had lost small amounts of silica and sodium by leaching of the glass shards; (2) the various phases of the dense welded tuff are all very similar in their composition, as crystallization from a vapor phase had no measurable effect on the bulk composition of the rocks; and (3) only a very local redistribution of the major elements and oxidation of the iron in the vapor-phase crystallization zone appear to have been involved.

Structure of Timber Mountain caldera, Nevada

W. J. Carr (p. B16–B19) has found that the center of Timber Mountain caldera, on the western edge of the Nevada Test Site, northeast of Beatty, is a structural dome in a thick sequence of ash-flow tuffs. These tuffs were intensely faulted in two episodes. The first resulted in an arcuate system of faults that were intruded by possible ring dikes, the surface expression of which is a group of light-colored porphyritic syenite intrusions that follow a part of the ring-fracture system. The second episode of faulting is expressed in a system of graben faults that resulted in irregular collapsed segments in the middle of the dome.

CENOZOIC STRATIGRAPHY

Pleistocene lake deposits subdivided around Searles Lake, Calif.

G. I. Smith, mapping upper Quaternary deposits in the south part of Searles Lake Valley, now exposed at a higher level than the salt deposits of Searles Lake, has delineated deposits formed in lakes believed to be of Yarmouth(?), Illinoian(?), Sangamon(?), early Wisconsin, middle Wisconsin, late Wisconsin, and Recent ages, and has found that some of these lakes had two or more distinct maxima. The mapping has also fixed the position of one fossil soil in this sequence as being immediately pre-Wisconsin in age, and several others as being of Wisconsin and Recent ages. All indicate a significant hiatus in the sedimentary history. Although not fossil soils in the strict sense, sedimentary features interpreted as fossil desert pavements that were covered with desert varnish have also been used as an indication of an hiatus in sedimentation. Recognition of such gaps is important in the study of this sequence of beds because the gaps are the lateral equivalent of the saline layers buried in the central part of the basin.

Revision of Lake Bonneville history

Roger Morrison has been able to make significant revisions in the accepted history of Pleistocene Lake Bonneville, and in the stratigraphy of the deposits laid down within it, as a result of intensive studies of a huge gravel pit at Little Valley, near the southern end of Promontory Point, Box Elder County, Utah. Two earlier lake cycles, comparable in magnitude to the well-known Lake Bonneville described by G. K. Gilbert, were probably Kansan and Illinoian, respectively. Included in the early history of the Lake Bonneville were two early lake cycles (recorded by the Alpine Formation) during which the lake rose nearly to the Bonneville (highest) shoreline, and which are correlated, principally on the basis of comparative maturity of soils, with the Bull Lake Glaciation in the Rocky Mountains. After long desiccation, there were three lake cycles in late Lake Bonneville time, all correlative with the Pinedale Glaciation. The first lake cycle nearly reached the Bonneville shoreline, the second reached this shoreline, and the third nearly reached the Provo level.

Pleistocene faulting at Salt Lake City, Utah

Richard Van Horn has found, in a building excavation in downtown Salt Lake City, Utah, sedimentary deposits that can be attributed to the Alpine Formation, corresponding to the early lake cycles and others that are correlated with the Bonneville Formation, of late Lake Bonneville time. The latest of these formations was faulted, but the faulting occurred before the development of a soil profile by weathering in post-Bonneville time. The possibility that younger faults may exist elsewhere in the Salt Lake area is not excluded by this evidence.

Pliocene and Pleistocene drainage changes in Arizona

M. E. Cooley, on the basis of a study of the imbrication of pebbles and the lithology of gravels of Pliocene(?) age which are faulted and tilted, has interpreted the ancestral stages of the Salt River and the development of the Tonto Basin of Arizona. In the Tonto Basin these gravels are equivalent to or underlie fine-grained sedimentary rocks containing fossils of Pliocene age. The resulting interpretation is that the ancestral Salt River entered the Tonto Basin near the course of the present Salt River, flowed westward and northwestward through the basin, and left in a valley underlain principally by schist; it flowed through the Mazatzal Mountains near the Phoenix-Payson highway. The dacite and rhyolite flows and tuffs in the Globe-Superior area formed a barrier to streams and were responsible, in part, for the establishment of the ancestral Salt River across the Mazatzal Mountains. Later, this valley was blocked by basalt flows that were erupted between Bartlett Reservoir (on the Verde River) and the Mazatzal Mountains and forced the ancestral Salt River to leave the Tonto Basin by the channel now occupied by the river. The relief of the area in late Tertiary time was not as great as it is today, although the main mountain ranges and valleys were outlined. The Tonto Basin, Mazatzal Mountain, and other nearby mountains were formed largely as a result of large-scale normal faulting, which displaced the gravels, basalts, and older rocks.

GEOCHEMICAL EXPLORATION

Shallow intrusive suspected near Cortez, Nev.

Working in lower plate Silurian and Devonian rocks exposed in the Cortez window of the Roberts thrust about 4 miles north of Cortez, Nev., R. L. Erickson, Harold Masursky, A. P. Marranzino, U. Oda, and W. W. Janes (p. B92–B94), have found anomalous amounts of arsenic, antimony, and tungsten in fracture fillings and jasperoid in limestone. Discontinuous alined masses of skarn and abundant fine-grained quartz-bearing dike rocks in the window suggest that an intrusive mass lies at shallow depths beneath at least part of the area. The skarn consists of calcite marble with porphyroblasts of idocrase, grossularite, and scapolite (meionite) in crystals as much as 2 inches across. This is the most intense contact metamorphic aureole in the Cortez area and it suggests that the metal anomalies may be leakage haloes emanating from concealed metalliferous deposits near the contact with the postulated buried intrusive.

Geochemical trends in Ruth copper district, Nevada

G. B. Gott and J. H. McCarthy, Jr., who have been carrying on geochemical investigations of the Ruth porphyry copper district, Nevada, are able to show that the district is well defined by the distribution of tellurium. Relatively small amounts (0.1–1 parts per million) of tellurium are present in the area where copper has been mined, and an irregular broad tellurium halo surrounds the central copper area. Iron- and manganese-rock material contains up to 1 percent tellurium. Silver and mercury show almost identical geochemical patterns.

These investigations also shows that the district is zoned in the following manner: Copper is the predominant metal in the central core; the core is surrounded by a zone in which zinc predominates, and this in turn is surrounded by a zone in which lead predominates.

COLUMBIA PLATEAU AND SNAKE RIVER PLAIN

Three members of Yakima Basalt in Washington

K. L. Walters and J. W. Bingham have recognized the upper three members of the Yakima Basalt in eastern Franklin and Whitman Counties, southeastern Washington. Although the thickness and number of the flows in each member differ from place to place, the characteristic lithology, joint pattern, and relative stratigraphic position of the members remain consistent throughout the 175 miles between the canyon of the Yakima River and eastern Whitman County.

Facies changes in Dalles Formation in Oregon

Eastward from the flank of the Cascade Range in north-central Oregon, R. C. Newcomb has found a progressive change in the lithologic character of the Dalles Formation, which overlies the Columbia River Basalt. The Dallas Formation changes from coarse pumiceous agglomerate with some andesite clasts on the west to fine-grained andesine lithic-vitric tuff in the canyon of the Deschutes River. Farther east, the tuff beds intertongue with pebble and cobble conglomerate, and at the east edge of the Wishram quadrangle the Dalles Formation resembles the Arlington Beds of Shotwell, 26 miles farther east. The middle Pliocene (Hemphillian) age assigned the Arlington Beds by Shotwell, however, is not in accord with the early Pliocene age commonly assigned to the Dalles Formation.

Oldest strata of Harney basin, Oregon, dated

Along the southern margin of the Harney basin, southeastern Oregon, widespread crystal-vitric and pumice-lapilli welded tuffs are interstratified with tuffaceous sedimentary rocks that, in one place low in the sequence, contain lower Pliocene vertebrate fossils, according to G. W. Walker and C. A. Repenning. A welded tuff layer in this sequence has a K-Ar age of about 9.7 million years. Near the basin, these lower Pliocene rocks lap with slight angular discordance onto sedimentary rocks that contain upper Miocene vertebrate fossils and onto basalt flows that overlie the upper Miocene rocks. The Pliocene rocks seem to be the oldest strata deposited in the Harney basin itself.

Ash from Crater Lake traced as far as Montana and British Columbia

Volcanic ash from the catastrophic Mazama eruption at Crater Lake, Oreg., about 6,700 years ago, has been traced by H. A. Powers and R. E. Wilcox (1-64) across Oregon, Washington, and Idaho, into Nevada, Montana, Alberta, and British Columbia. The petrographic and chemical characteristics of the Mazama ash distinguish it from other ash deposits in the Pacific Northwest, making it a recognizable stratigraphic marker, and, because it is well dated, an ideal geologic datum. Powers and Wilcox have found that most of the ash formerly called "Glacier Peak ash" in Washington, and "Galata ash" in Montana, is from the Mazama eruption. Glacier Peak Volcano in northern Washington was the source, however, of an ash bed of very late glacial or early postglacial age found locally in Washington, Idaho, and Montana.

Fault mapped along border of Snake River Plain

In the Mountain City quadrangle, northern Nevada, R. R. Coats has mapped a major normal fault near the northern margin of the mountainous part of the quadrangle; the fault trends about N. 70° E. and is thrown down on the north. This fault, and other faults of probable similar trend in the Jarbidge quadrangle, are roughly parallel to the mountainous belt along the southern border of the Snake River Plain eastward as far as Salmon Falls Creek. Coats suggests that the mountains and the Snake River Plain in this region may have been outlined by faulting as early as the Miocene.

Gravity survey of Arco area, Snake River Plain

A reconnaissance gravity survey of the National Reactor Testing Station, Idaho, near the northern margin of the Snake River Plain shows that a gravity low extends from the south end of the valley of the Little Lost River around the east and south sides of the Arco Hills. D. R. Mabey interprets this low as indicating that a large volume of sediments of low density are interbedded with the basalt at the north edge of the plain. A gravity high over the Lost River Sinks indicates that the sediments are less abundant there. Gravity anomalies appear to correlate generally with magnetic anomalies, suggesting that both the gravity and magnetic highs are produced by dense basalt.

Structural features extend beneath Snake River Plain from the north

North of the National Reactor Testing Station, Idaho, roughly parallel northwest-trending fault-controlled basins and ranges intersect the Snake River Plain. Preliminary gravity and aeromagnetic profiles drawn by G. H. Chase suggest that the roots of such structures, although possibly downfaulted at the margin of the Snake River Plain, extend into the plain beneath the sequence of basalt flows and intercalated sediments. According to D. A. Morris, northwest-trending faults locally cut Quaternary basalt flows and alluvial fans north of the station. Either this faulting or intraflow lensing of sediments within the basalt has produced a barrier that materially affects the movement of ground water in the eastern part of the station.

Overflow of Lake Bonneville estimated

At a time of pluvial climate about 90,000 years ago, Lake Bonneville overflowed at Red Rock Pass near Preston, Idaho, and discharged 1.3 billion acre-feet of water onto the Snake River Plain. The resulting flood inundated an area of 250 square miles between Pocatello and American Falls, covered an area of 170 square miles near Rupert, and filled the canyon in the next 200 miles downstream to a depth of 300 feet. Calculations of discharge by C. T. Jenkins at constricted sections along the canyon south of Boise, determined from height of flood deposits and from hydraulic principles, indicate a maximum discharge of 15 million cubic feet per second—a flow about 5 times the estimated mean annual discharge of the Amazon. This extraordinary flood caused spectacular erosion at the canyon head near Twin Falls, where cutting of cataracts and marginal spillways removed at least 50 billion cubic feet of basalt. This rock was washed downstream and deposited in wide segments along the canyon as enormous bars of boulders and sand. Some of the bars reach 300 feet above the Snake River and are several miles long. Because of relatively tranquil flow of deep water through the wide segments (owing to constrictions downstream), virtually all of the flood debris was dropped in the 120-mile stretch below Twin Falls. The volume of gravel therefore can be equated with the amount of flood erosion. Moreover, the distribution and physiography of the flood debris give an accurate picture of the width, the profile, and the pattern of flow of this gigantic flood. Thus, geologic study and mapping contribute empirically to the hydrologic assessment of a discharge vastly beyond the range of experimental measurement.

PACIFIC COAST REGION

WASHINGTON

Geology of Mount Rainier

The geology of Mount Rainier National Park, the site of one of the most impressive volcanic edifices in the Cascade Range, is described in a report by R. S. Fiske, C. A. Hopson, and A. C. Waters (1–63). The bulk of Mount Rainier volcano, composed chiefly of pyroxene andesite flows and breccias, grew during Pleistocene time. These flows and breccias were extruded on an irregular mountainous surface underlain by a complex of altered volcanic and sedimentary rocks of Eocene to Miocene age and plutonic and hypabyssal igneous rocks of the late Miocene Tatoosh pluton. Mount Rainier probably last erupted about 500–600 years ago, but is now dormant and is clad by glaciers and snowfields. Glacial erosion, rockfalls, and avalanches are rapidly reducing the size of the mountain.

Plutons of Northern Cascade Mountains

F. W. Cater, D. F. Crowder, and others have recently completed studies of the Coast Range batholith between Glacier Peak and Lake Chelan. These studies have resulted in the delineation of 20 major plutons and many smaller stocks which occur within medium-grade metamorphic rocks of the Northern Cascade Mountains. The older plutons are dominantly elongate and commonly gneissic parallel to the regional northwest trend of foliation and compositional layering in the surrounding rocks. These older plutons range in composition from tonalite, the dominant rock, to granodiorite. Radiometric age determinations suggest a Cretaceous age for the large pluton at Chelan, known as the "Chelan batholith." Four of the older plutons are interpreted as having formed in place by granitization, whereas others may be magmatic intrusives emplaced before or during regional metamorphism. The youngest bodies, which are widely distributed and largely discordant, are massive, shallow, magmatic intrusions of late Miocene age. They range from tonalite to adamellite in composition. Recent radiometric age determinations have also distinguished a late Eocene pluton that consists largely of granodiorite, was emplaced at moderate depth, and is dominantly concordant.

Structural history of eastern Olympic Mountains

New data bearing upon the structural history of the eastern Olympic Mountains resulted from mapping by W. M. Cady and R. W. Tabor of large asymmetrical folds with limbs about a mile wide, west of Mount Constance. These folds plunge steeply northwest and are outlined by distinctive graywacke beds interlayered with slate in a thick sedimentary section west of and stratigraphically below the nearly vertical homoclinal sequence of volcanic rocks of the Crescent Formation. The Crescent volcanics, which encircle the Olympics on the north, east, and south, were not involved in the folding, thus indicating a strong tectonic break between the graywacke-slate sedimentary section and the volcanic rocks. Steep axes of numerous smaller folds and related cleavage-bedding intersections occur in the graywacke-slate sequence elsewhere in the eastern Olympics, and their distribution, orientation, and movement sense are under systematic study. The confinement of the steeply plunging folds to the graywacke-slate sequence suggests a possible analogy with salt domes, wherein the complexly folded salt may correspond to the folded interbedded graywacke and slate, and the Crescent volcanics may correspond to the resistant caprock.

Glaciation of southwestern Olympic Mountains

Valleys heading on the southwestern side of the Olympic Mountains were occupied by glaciers three times during Wisconsin time, and at least once in pre-Wisconsin time, according to D. R. Crandell (p. B135–B139). During all but the last of these glaciations, the interior of the mountains probably was mantled by extensive icefields, if not by a continuous icecap above which only the highest ridges and peaks protruded. Some of the glaciers extended westward as broad lobes and reached the present Pacific shoreline.

Continuing studies of urban geology in and around the city of Seattle, by D. R. Mullineaux and H. H. Waldron, have established the existence of late Pleistocene, pre-Vashon, nonglacial sediments that range in age from about 18,000 to 24,000 years, as determined by radiocarbon dating methods. In addition, the existence of previously unknown older sediments of glaciomarine origin has also been established. Both of these discoveries are a significant contribution toward an understanding of the sequence of events that occurred in the Pacific Northwest during the Pleistocene Epoch.

OREGON

Geologic mapping of Portland area

A report on the geology of the Portland area by D. E. Trimble (1–63) not only contributes to the knowledge of the general geology of northwest Oregon, but also provides basic geologic data broadly applicable by the construction industry to urban development of the region. The more than 1,000 square miles in the area mapped around Portland is underlain mainly by Cenozoic terrestrial deposits and volcanic rocks; a small granodiorite stock crops out in the northwestern part, and the marine Scappoose Formation crops out in the northwestern part. Included in the Quaternary sediments are the products of a large-scale flood, believed to have resulted from the sudden release of water from glacial Lake Missoula; other somewhat older alluvial units consist of mudflow deposits, bouldery gravel, and loess. Most deposits older than late Pleistocene are deeply weathered. The structural instability of loess and weathered material, when wet, poses most of the foundation problems for the construction industry in this region.

Eocene volcanoes of Oregon coast

Geologic mapping along the central Oregon coast, by P. D. Snavely, Jr., and N. S. MacLeod, together with petrographic studies and new chemical analyses, indicates that volcanoes that erupted along the axial parts of the Oregon-Washington Tertiary eugeosyncline during early to middle Eocene time followed a life cycle somewhat similar to that of volcanoes in the Hawaiian Islands. Great volumes of saturated theoleiitic basalt were erupted onto the sea floor to form pillow flows and breccia in early Eocene time. In areas of thickest accumulation, islands were constructed and a pyroclastic phase formed thick units of tuff and tuffaceous siltstone adjacent to the islands. During the waning periods of volcanism the magma was probably contained within shallow reservoirs beneath the volcanic centers, where it differentiated to form augite-rich basalt and alkalic basalt. Surface or near-surface occurrences of these lower to middle Eocene basaltic rocks produce broad gravity highs and sharp, high-amplitude magnetic-anomaly zones.

COAST RANGES AND KLAMATH MOUNTAINS OF NORTHERN CALIFORNIA AND SOUTHERN OREGON

Hypothesis for distribution of ultramafic rocks

Anomalous distribution of the pre-Tertiary rocks of northwestern California and southwestern Oregon may be a result of regional thrust faulting, according to an hypothesis advanced by W. P. Irwin (p. C1–C9). According to this hypothesis, extensive linear belts that crop out in the area of ultramafic rocks are the exposed edges of sheetlike intrusions that lie between the postulated thrust plates, and have root zones to the east. The ultramafic sheets intruded the rocks of the Klamath Mountains during the Late Jurassic (Nevadan orogeny), and those of the Coast Ranges probably during the Late Cretaceous. Emplacement of the principal ultramafic sheet of the Coast Ranges is thought to have been along a regional thrust fault formed prior to the development of the San Andreas fault system, and to have resulted from a different force couple than the

San Andreas. Thus, if the emplacement of the Coast Range ultramafic sheet can be accurately dated, it may indicate a limit to the maximum age of the San Andreas fault system.

G. A. Thompson's gravity investigations of large ultramafic masses in the northern Coast Ranges of California, in the Cazadero and Red Mountain areas, indicate that these bodies extend only to relatively shallow depths. The geophysical data are compatible with the suggestions of Irwin that these rocks constitute thrust plates resting on the Franciscan or Dothan Formations.

Regional gravity anomalies in southwestern Oregon

Data from some 2,250 gravity stations in southwestern Oregon have been reduced to simple Bouguer values in a regional study by H. R. Blank, Jr. The Bouguer gravity field in the area between the Oregon coast and the Klamath graben, just east of the Cascade Range, has a total relief of about 210 milligals. An overall east-to-west gradient of about −1 mgal per mile is closely related to an increase in average elevation toward the east, and may therefore be largely attributed to crustal thickening to the east away from the continental margin, under conditions of approximate isostatic equilibrium. Ultramafic rocks and lower Eocene volcanics, which occur along a linear gravity high, may reflect a major north-trending fracture zone in southwestern Oregon that may be an extention of the Powers fault zone, as postulated earlier by P. D. Snavely. According to Blank there was no residual positive anomaly associated with Klamath Mountain rocks west of the Powers fault zone in southwestern Oregon. In the Klamath Mountains province, a gravity low is associated with the north-trending belt of sedimentary rocks of the Dothan Formation, and a gravity high with the heterogeneous rocks to the east.

Glaucophane schist localized along thrust faults in Coast Range

In the northern Coast Ranges, R. D. Brown, Jr., has mapped a gently south-dipping, virtually tabular mass of glaucophane schist more than 8 miles long extending southeastward from Goat Mountain in the southwestern corner of the Stonyford quadrangle. The schist body appears to lie along the southern extension of a folded thrust fault. Other numerous small exotic bodies of glaucophane schist are also found along this and other thrust surfaces. The field evidence thus suggests a close relation between thrusting and the tabular body of glaucophane schist, which parallels the thrust surfaces.

Metamorphic facies of Triassic rocks along Oregon border

Mapping and petrographic studies by P. E. Hotz in the Condrey Mountain quadrangle, Siskiyou County, Calif., have shown a generally zonal arrangement of metamorphic facies in a regionally metamorphosed terrane. Rocks of the Triassic Applegate Group, which are in the greenschist facies, overlie more highly metamorphosed mafic and quartzo-feldspathic rocks, which are in the almandine-amphibolite metamorphic facies. Indications of a progressive increase in the metamorphic grade of rocks of the greenschist facies toward those of a higher grade can be seen, but the increase cannot be positively demonstrated because the two assemblages are separated by a zone of shearing along which a large sill and many small bodies of granitic rock have been emplaced. Rocks of the almandine-amphibolite facies are thrust over a central core of quartz-muscovite and albite-chlorite-epidote schists belonging to the lower part of the greenschist facies.

Thrust inferred in northern Coast Ranges, Calif.

R. D. Brown (1–64) has interpreted a klippe of volcanic rock covering 50 square miles in Glenn, Colusa, and Lake Counties, Calif., as evidence of a folded thrust fault that can be traced eastward into the Stony Creek fault zone. Rocks involved in the thrusting are of Late Jurassic and Cretaceous age.

Sulfide deposits mapped in West Shasta district

The geology of the western part of the West Shasta copper-zinc district, Shasta County, Calif., is shown on a new map of the French Gulch quadrangle by J. P. Albers, A. R. Kinkel, Jr., A. A. Drake, and W. P. Irwin (3–64). The eastern part of this map is a reinterpretation by Albers of earlier work by Kinkel and others.[47] The quadrangle contains several large sulfide deposits and numerous gold deposits, none of which are being worked at present.

Age data of glaucophane schist in California

Isotopic age determinations of muscovite from glaucophane schist of the Franciscan Formation near Cazadero, Calif., range from 130 to 150 million years. Donald E. Lee, H. H. Thomas, R. F. Marvin, and R. G. Coleman (1–64) conclude that the 5 K–Ar ages and 1 Rb–Sr age indicate the time of recrystallization of tectonic blocks and bedrock schist during a Late Jurassic and Early Cretaceous metamorphic event.

[47] A. R. Kinkel, Jr., W. E. Hall, and J. P. Albers, 1956, Geology and base-metal deposits of West Shasta copper-zinc district, Shasta County, California: U.S. Geol. Survey Prof. Paper 285, 156 p.

SOUTHERN CASCADE RANGE AND SIERRA NEVADA OF CALIFORNIA

Volcanic history of area north of Lassen Peak

Geologic mapping by G. A. Mcdonald (1–63) in the vicinity of Lassen Volcanic National Park has been carried eastward from the Manzanita Lake and Prospect Peak quadrangles through the Harvey Mountain quadrangle, thus adding to the strip extending across the southern end of the Cascade Range into the Great Basin. The rocks delineated are largely volcanics of Pleistocene and Recent age, and include some of the youngest volcanic rocks of the conterminous United States. A series of very late Pliocene(?) andesite and rhyodacite lava flows was folded along nearly east-west axes, and later broken by faults trending nearly northward and northwestward. These flows were subsequently covered by another series of volcanic rocks that range in composition from basalt to dacite. The volcanic activity of the quadrangles mapped, which do not include Lassen Peak, continued into historic time; the most recent eruption was in 1851 at Cinder Cone, northeast of Lassen Peak. Block faulting continued through early Pleistocene, but ceased before late Pleistocene time.

Ages of metamorphic rocks of western Sierra Nevada

Reconnaissance geologic mapping by L. D. Clark and N. K. Huber in the northern part of the western Sierra Nevada metamorphic belt has resulted in stratigraphic reassignment of large areas of rock that were previously believed to be of Paleozoic age. Some bodies of limestone that contain late Paleozoic fossils are now recognized as slumped blocks, rather than lenses that formed in situ. The blocks were emplaced by subaqueous mudflows during the Late Jurassic. Similar slumped blocks containing Paleozoic fossils were also mapped farther south within the Jurassic Mariposa Formation in the San Andreas quadrangle by Clark, A. A. Stromquist, and D. B. Tatlock (1–63). The transported fossiliferous blocks were previously thought to indicate the true age of the deposits in which they are now situated.

Aeromagnetic mapping in Mother Lode belt

Analysis of an aeromagnetic survey in the central Mother Lode belt, by J. R. Henderson, A. A. Stromquist, and Anna Jesperson, suggests that most of the major positive magnetic anomalies are associated with ultramafic bodies. Many of these ultramafic bodies in the area are associated with major fault zones, and the trend of at least one, the Melones fault zone, is reflected by a linear belt of magnetic anomalies. An east-west elongate magnetic anomaly in the southwestern part of the Valley Springs quadrangle suggests the existence of a deeply buried ultramafic mass at the east edge of the San Joaquin Valley. This anomaly is of particular interest, as its trend is remarkably different from that correlated with structures exposed in the foothills belt.

Geology of central Sierra Nevada summarized

P. C. Bateman, L. D. Clark, N. K. Huber, J. G. Moore, and C. D. Rhinehart (1–63) have summarized their geologic findings along a belt across the central part of the Sierra Nevada. Emphasis in the report is on the compound nature of the Sierra Nevada batholith and the mode and environment of its emplacement. A geologic map, at a scale of 1:250,000, shows the distribution of individual plutons and adjacent country rock in those areas which have been mapped geologically in some detail. K–Ar and Rb–Sr age studies by R. W. Kistler, P. C. Bateman, and W. W. Brannock (1–64) indicate an age of 85 to 90 million years for the Mount Givens and Lamarck Granodiorites of the batholith. Together with the probably correlative Half Dome Quartz Monzonite, and the younger Cathedral Peak Granite of the Yosemite region, these rocks comprise a northwest-trending central belt along and just west of the Sierra Nevada crest, averaging 20 miles in width and at least 80 miles in length. Older granitic rocks on both sides of this belt yield discordant K–Ar mineral ages that have been irregularly reduced as a result of reheating of the rock at the time of intrusion of the more centrally located younger plutons. K–Ar ages of hornblendes from the Tinemaha Granodiorite, one of the older plutons, range from 150 to 180 million years and indicate that some of the plutons which make up the batholith are at least as old as Jurassic.

Isotope ratios of Sierra Nevada granitic rocks

Analysis of Sr^{87}–Sr^{86} and Rb–Sr ratios from whole-rock samples of granitic rocks from many of the same plutons mentioned above suggests an initial Sr^{87}–Sr^{86} ratio of 0.7075. Bateman, in collaboration with P. M. Hurley and others at the Massachusetts Institute of Technology (1–64), interprets this ratio as indicating that the Sierra Nevada granitic magmas were not direct simple derivatives of the typical mantle-source regions of oceanic basalt (ratio about 0.704), nor were they dominantly formed by fusion of typical marine shales of a period or two earlier age (ratio >0.710). The initial ratio is compatible with the hypothesis that the granitic magmas were formed by anatexis in a geosyncline containing much volcanic material and some terrigenous sialic detritus. It is also compatible with a magmatic derivation from a very ancient basalt.

Metasedimentary rocks of the east flank of the Sierra Nevada

In the Mount Morrison quadrangle, C. D. Rinehart and D. C. Ross (1–64) have studied and described a thick section of metamorphosed Paleozoic sedimentary rocks and Mesozoic volcanic rocks that are exposed in a roof pendant on the steep eastern flank of the Sierra Nevada and that together total 50,000 feet in thickness. The metasedimentary sequence, about 32,000 feet thick, is composed chiefly of pelitic and siliceous hornfels interbedded with subordinate amounts of calcareous rocks. Fossils indicate that the metasedimentary rocks range in age from Ordovician to Permian(?). Lithologically and faunally the pre-Pennsylvanian strata are transitional between the carbonate and detrital-volcanic assemblages of the Great Basin; the Pennsylvanian to Permian(?) strata contain a much higher proportion of clastic material than the dominantly carbonate assemblages of similar age 50 miles to the southeast.

Permian volcanism in eastern Sierra Nevada

Five samples from a thick unit of metavolcanic rocks, lying between fossiliferous metasedimentary rocks of Pennsylvanian and Permian(?) age and fossiliferous metavolcanic and metasedimentary rocks of Early Jurassic age, were determined by C. E. Hedge to be of Permian age (230–265 million years) by the Rb–Sr whole-rock dating technique. This metavolcanic unit, which has been mapped in the Ritter Range roof pendant by C. D. Rinehart, N. K. Huber, and R. W. Kistler, is the first evidence of pre-Mesozoic volcanism in the east-central Sierra Nevada.

CENTRAL AND SOUTHWESTERN CALIFORNIA

Aerial radioactivity survey of central California

Compilation of data by K. G. Books from an aerial radioactivity survey in the San Francisco-Central Valley region indicates that the intensity of radioactivity in the area is moderate. It is highest in areas underlain by igneous rocks and has the greatest variation in the Coast Ranges, where rocks of diverse compositions are present. In a large part of the area a low intensity of radioactivity reflects an extensive alluvial cover, much of which has a high water content with a correspondingly strong masking effect.

Upper Tertiary sequence of Salinas Valley revised

Stratigraphic and paleontologic study of upper Tertiary strata in the southern Salinas Valley, Monterey and San Luis Obispo Counties, Calif., by D. L. Durham and W. O. Addicott, indicates that the upper Miocene Santa Margarita Formation intertongues with the Monterey Shale northward from the south end of the valley. Certain strata in Monterey County, previously assigned to the Santa Margarita Formation, belong instead to a newly defined Pliocene formation.

Structural interpretation of Santa Monica Mountains

Geologic mapping in the Santa Monica Mountains by R. H. Campbell, R. F. Yerkes, and C. M. Wentworth has resulted in a better understanding of this structurally complex area. The south flank of the Santa Monica Mountains is traversed by the east-west-trending Malibu Coast fault, which forms the boundary between the Transverse Ranges province to the north and the Peninsular Ranges province to the south. Structural and stratigraphic evidence indicates that the Malibu Coast fault is chiefly a reverse fault, with the north block relatively upthrown. North of the fault are four major structural elements—three major thrust sheets and an autochthonous block. The superimposed thrust sheets form a sequence of tectonic layers which was subsequently folded, faulted, dilated by the intrusion of mafic igneous rock, and truncated by the Malibu Coast fault.

Fossil vertebrates in Barstow Formation

From a study of the fossil vertebrates in the Barstow Formation of the Mojave Desert of southern California, G. E. Lewis has concluded (1–64) that: (1) the uppermost third of the formation definitely corresponds to a zone containing a faunal assemblage usually considered to be late Miocene in age; (2) the middle third of the formation may correspond to a zone containing an assemblage usually thought to occupy a middle Miocene stratigraphic position; and (3) the lower third of the formation contains no identified fossils, and is of unknown age but not younger than Middle Miocene.

Geologic mapping of San Nicolas Island

The geology of San Nicolas Island, the outermost of the Channel Island group, has been described by J. G. Vedder and R. M. Norris (1–63). The stratigraphic section on the island consists of nearly 3,500 feet of folded and faulted sedimentary rocks of Eocene age which are partially concealed by surficial marine terrace deposits and dune sand of late Pleistocene and Recent age. Structurally, the rocks comprise a broad, complexly faulted anticline whose crest is near the southwest shoreline. The anticline roughly parallels the long dimension of the island and plunges gently southeast.

ALASKA

Figure 6 is an index map of Alaska showing the boundaries of the regions referred to in the following summary of scientific and economic findings of recent geologic and geophysical studies.

NORTHERN ALASKA

Mapping in Point Hope area

A traverse across the structural saddle between the Lisburne Hills and the nose of the DeLong Mountains by I. L. Tailleur completed preliminary fieldwork in the Point Hope and DeLong Mountains quadrangles of northwestern Alaska. The previously undescribed east flank of the saddle consists of a dark, fine-grained facies of the Mississippian Lisburne Group overlain by a late Paleozoic and early Mesozoic complex of chert, some of which contains oil shale. The middle Cretaceous rocks filling the saddle consist of several different graywacke-mudstone assemblages, none of which could be differentiated as a map unit along the traverse. Folding is intense along a northerly to northeasterly grain, but no large-scale faulting was recognized.

Tiglukpuk Formation yields Lower Cretaceous fossils

Stratigraphic and structural studies by Arthur Grantz and W. W. Patton, Jr., in the Tiglukpuk Creek area and study of new fossil collections by D. L. Jones indicate that the structurally complex Tiglukpuk Formation, previously assigned to Upper Jurassic, is at least in part Lower Cretaceous. The stratigraphic relations of the Tiglukpuk Formation and the possibly

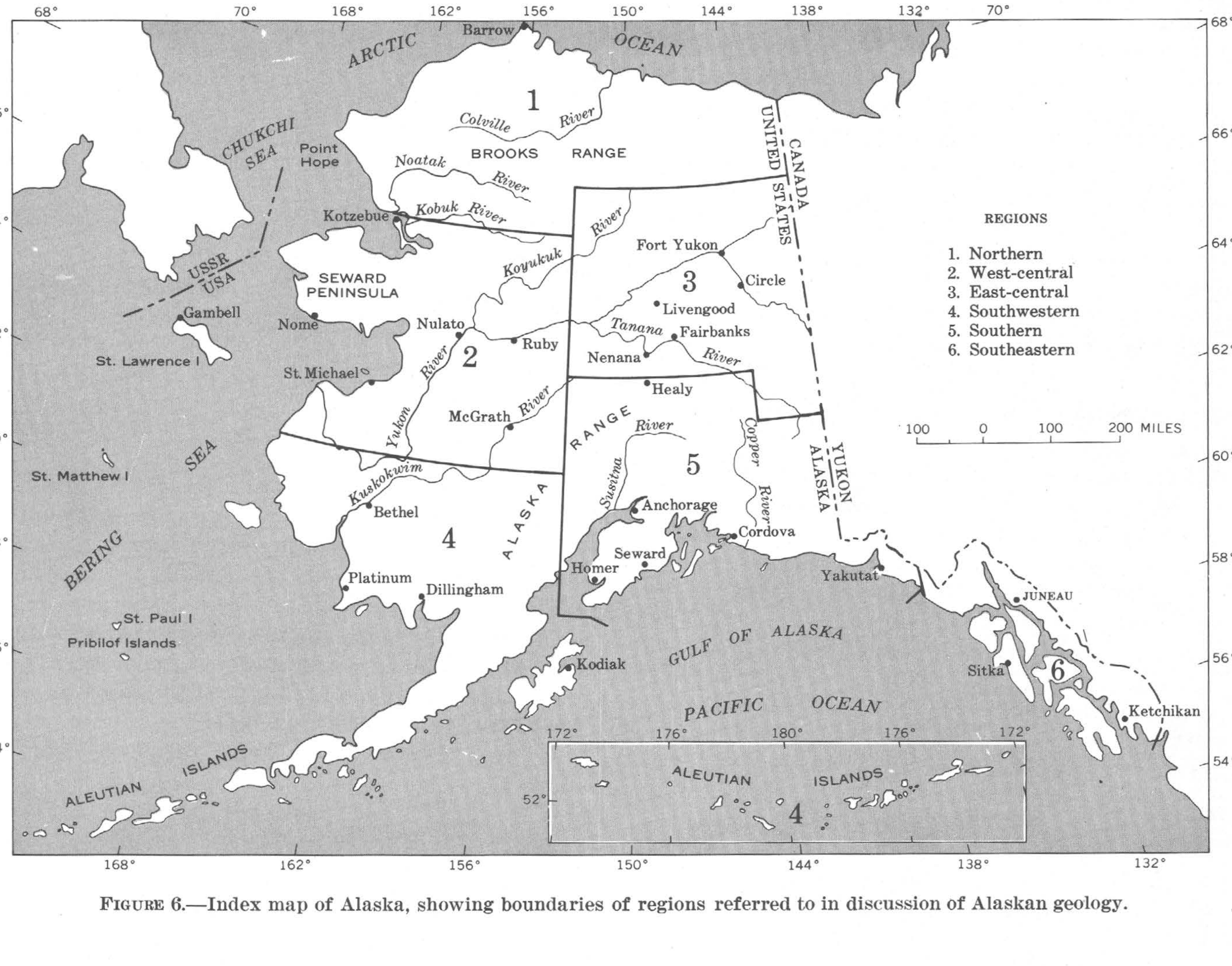

FIGURE 6.—Index map of Alaska, showing boundaries of regions referred to in discussion of Alaskan geology.

correlative Lower Cretaceous Okpikruak Formation have not been determined, pending a restudy of earlier fossil collections and additional fieldwork. New fossil collections from the unnamed sequence of tuffaceous graywacke along Tiglukpuk Creek confirm the Middle Jurassic age of these beds and rule out the possibility that they may overlie the Tiglukpuk Formation, as suggested previously by W. W. Patton and I. L. Tailleur.

Triassic rocks of Brooks Range

Reconnaissance study of Triassic exposures along the north front of the Brooks Range by N. J. Silberling and W. W. Patton, Jr., demonstrates that the "shale member" of the Shublik Formation, as defined by Patton and I. L. Tailleur in the Killik-Itkillik region, is at least partly a temporal equivalent of the Ivishak Member of the Sadlerochit Formation, which underlies the typical Shublik Formation farther east in the Shaviovik-Sagavanirktok region. The "shale member" was traced eastward to a point several miles south of Sagavanirktok Lake and was found to be characterized by a middle Lower Triassic fauna including *Euflemingites romunduri* Tozer, *Posidonia mimer* Oeberg, and "*Pseudomonotis*" *boreas* Oeberg. This same fauna has been collected by oil company geologists in the upper part of the Ivishak Member about 10 miles north of Sagavanirktok Lake. As no transition occurs between the lithologically different "shale member" of the Shublik and Ivishak Member of the Sadlerochit, despite the proximity of their correlative outcrops near Sagavanirktok Lake, they may belong to different structural units that were juxtaposed during deformation of the region.

Oil-rich shales found in Nuka-Etivluk Rivers region

Samples of oil shale from the Nuka-Etivluk Rivers region in northern Alaska assay 26–146 gallons of oil per ton (Tailleur, 1–64). They were collected from beds as much as a few feet thick that are associated with beds of varicolored chert in the post-Triassic, pre-Berriasian (Cretaceous) stratigraphic interval. Similar organic shale has been found more than 100 miles to the west and to the east of the region. Too little is yet known about the deposits to judge the importance of the relatively high oil content.

WEST-CENTRAL ALASKA

Mapping in Kobuk–upper Koyukuk basin

Investigations of the Kokub–upper Koyukuk Cretaceous basin, a possible petroleum province, were begun in the Hughes quadrangle by W. W. Patton, Jr., and T. P. Miller. Preliminary mapping indicates that the areal extent of possibly favorable basin sediments in the Hughes quadrangle is more limited than previously thought. Southeast of the Koyukuk River, large areas of the sedimentary rock have been invaded and metamorphosed by granitic intrusives, and in the eastern Lockwood Hills the basin sediments have been stripped off a broad structural high which exposes lower Cretaceous volcanic rocks. The basin sedimentary sequence consists of marine graywacke and mudstone with a narrow band of continental quartzose sandstone and conglomerate along the northern edge of the basin. The sedimentary rocks were found to be complexly folded and faulted nearly everywhere in the basin.

Pleistocene history of Bering Strait area

Studies of marine sediments in western Alaska by D. S. McCulloch, D. M. Hopkins, and F. S. MacNeil have resulted in the recognition of a record of seven marine transgressions since the beginning of the Pleistocene Epoch. The oldest deposits contain faunas suggestive of relatively warm-water temperatures; many of the species differ significantly from their nearest living relatives. Successively younger faunas of early and middle Pleistocene age become successively more similar to the modern faunas of adjoining waters; the rich fauna contained in the youngest of the middle Pleistocene marine sequences is identical with the modern fauna of adjoining waters. However, late Pleistocene faunas of Sangamon age, though composed mostly or entirely of living forms, contain a few species that now live only in areas farther south, indicating that sea temperatures were warmer during Sangamon time than at present.

A comparison between the stratigraphy and faunas of Quaternary marine deposits in Chukotsk Peninsula (U.S.S.R.) and western Alaska indicates that no early Pleistocene marine deposits have yet been found in the Chukotsk area, although deposits representing two early Pleistocene marine transgressions are recognized in Alaska. Each middle and late Quaternary transgression is represented in the Chukotsk area by sediments containing faunas suggesting colder water temperatures than the faunas found in deposits of the same transgression in Alaska; this indicates that the present contrast in water temperatures in coastal waters of the Chukotsk Peninsula and Alaska has existed during each middle and late Pleistocene marine transgression and presumably that current systems in Bering and Chukchi Seas were similar during middle and late Pleistocene times to those at present.

D. S. McCulloch found evidence on the Baldwin Peninsula for a warm late glacial to early postglacial period. This evidence is (1) a buried discontinuous wood-rich zone in a now treeless area, (2) the habitation by beaver beyond their modern range, and (3) evidence for a period when ice wedges melted. Radiocarbon dates suggest that the warm period started after 11,340±400 years ago and encompassed the interval from 9,020±350 to 7,270±350 years ago.

Detailed study by C. L. Sainsbury of the deposits on the York Terrace, a marine platform of the western Seward Peninsula, has yielded information and fossils which lead to the conclusion that the terrace was uplifted to its present height of about 600 feet in post-Yarmouth, pre-Wisconsin time. Because the terrace extends west to the Bering Strait, which has been considered the most likely route of migration of plants and land animals between Siberia and Alaska, Sainsbury regards it as probable that the Bering Strait was a seaway throughout early Pleistocene time until the uplift which raised the terrace, and hence migrations by land were restricted to late Pleistocene time.

Laumontitized sedimentary rocks widespread

J. M. Hoare, W. H. Condon, and W. W. Patton, Jr., (p. C74–C78) outlined an area of at least 2,000 square miles in western Alaska characterized by laumontitized sedimentary rocks of Cretaceous age Most of the laumontite is thought to have formed diagenetically through the reaction of water rich in calcium carbonate with tuffaceous material of acid or intermediate composition.

SOUTHWESTERN ALASKA

Biologic samples indicate ice-free biota refuge on Kodiak Island

Analyses by Thor Karlstrom of biologic samples collected on Kodiak Island in 1962 by Drs. Eric Hulten, botanist, and Carl Lindroth, zoologist, of Sweden; Dr. Ball, entomologist, of Canada; and Dr. Rausch, mammalogist, of Anchorage; have been completed. The biologic results in general support the geologic data of an ice-free area, a potential biota refuge, that persisted on the island during at least the last two major glaciations. The character of the flowering plants, invertebrate fauna, and fish of the island strongly suggest survival of some of these forms during glacial maxima in such an isolated refugium. The evidence of the mosses, lichen, algae, and mammals, however, is not so clear cut, and it is possible that many of these forms migrated to the island in postglacial time.

Reconstruction of the refugium from the geologic data indicates a mountainous ice-free area with major valleys largely occupied by proglacial lakes and in all probability characterized by an austere arctic-type climate. In keeping with this reconstruction, the plants and animals that suggest persistence and survival in the refugium are all of arctic type.

Ultramafic rocks found on Kodiak Island

Four ultramafic bodies were discovered by G. W. Moore on the northwest coast of Kodiak Island during the course of reconnaissance mapping. The bodies occur along a line extending from Middle Cape to Broken Point, and the largest, at Middle Cape, is about 3 miles in diameter. The bodies consist of partly serpentinized dunite, pyroxenite, and banded gabbro. Ultramafic rocks had not previously been known on Kodiak Island, but these bodies are probably an extension of a belt of similar rocks on the Kenai Peninsula. Mining properties at Red Mountain and Flame Point on the Kenai Peninsula have been responsible for all of Alaska's chromite production.

EAST-CENTRAL ALASKA

Dating of uplift of Alaska Range

Field investigation by Clyde Wahrhaftig, J. A. Wolfe, and E. B. Leopold in the Fairbanks A–3 quadrangle disclosed a tuff bed about 50 feet thick. The tuff was erupted from some unknown but nearby source at the beginning of the time when the south-flowing drainage across the site of the Alaska Range was dammed and diverted by the rising of the mountains that constitute the present Alaska Range. The uplift of the range is recorded in the Nenana Gravel, a 4,000-foot-thick alluvial-fan accumulation, whose constituent pebbles can be traced to sources in the range. Dating the ash will put a lower limit on the rate of deformation of the Alaska Range, as the plant fossils associated with it are regarded by Wolfe as probably early Pliocene in age, and the deposition and subsequent deformation of the Nenana Gravel were completed well before the first of four distinct glacial advances in the Alaska Range.

Gravity survey of Yukon Flats

Gravity traverses by D. F. Barnes and R. V. Allen along the upper Yukon, Porcupine, Chandalar, Sheenjek, and Black Rivers indicate that Bouguer gravity anomalies in the Yukon Flats range from 0 to −30 milligals, with the highest values covering a broad area in the southeastern portion of the flats. This provides additional evidence that no large sedimentary basin occurs beneath the alluvial cover of the Yukon Flats, although local sedimentary prisms may be indicated in the northern portion of the flats.

Cambrian history of Tatonduk-Nation Rivers area

Stratigraphically controlled collections of Cambrian fossils from the Tatonduk-Nation Rivers area by A. R. Palmer show that although the Cambrian section is probably less than 1,000 feet thick, most of the Middle and Late Cambrian faunas found in the Cordilleran sections of southern Canada and western conterminous United States are present. Striking facies and thickness changes within a few miles indicate a complicated Cambrian sedimentary history. The Early Cambrian faunas of Alaska include both material in place and faunas from boulders in a Middle Cambrian conglomerate. The trilobites in some of these faunas include several genera known also from Siberia. No olenellids or other typical Early Cambrian trilobites of the Cordilleran area have been found.

Kandik Basin proves smaller than expected

Mapping by E. E. Brabb and Michael Churkin indicates that the Kandik Basin, a possible petroleum province, is smaller than originally thought but nevertheless may contain petroleum. Possible oil-bearing structures in this basin have been mapped for the first time. A small amount of bitumen has been found in Paleozoic rocks cropping out at the margins of this basin, suggesting that oil may be trapped at depth.

Stratigraphy revised in Livengood and Christian quadrangles

Mapping by R. M. Chapman and F. R. Weber in the Livengood quadrangle, northeast of Fairbanks, indicates that two rock units near Wickersham dome, previously mapped as Precambrian Birch Creek Schist and an undifferentiated pre-Middle Ordovician unit, and thought to be separated by a thrust fault, are gradational. The younger unit, including distinctive red and green argillaceous rocks, seems to correlate with similar rocks, described by A. H. Brooks in 1900 as the Nilkoka Group, near the junction of the Tolovana and Tanana Rivers. The differentiation of an as yet unnamed late Middle or early Upper Devonian fossiliferous graywacke and shale unit by Weber and Bond Taber in the central part of the quadrangle, and the discovery of extensive unmapped Devonian(?) mafic intrusive rock units by Chapman, Weber, and Taber are also of regional significance.

According to W. P. Brosgé and H. N. Reiser, the basic igneous rocks that cover a 1200-square-mile area in the Christian quadrangle are not Devonian volcanic rocks as previously thought. The rocks are mostly gabbro and basalt sills with only minor flows. A preliminary radioisotope age determination by M. A. Lanphere shows that the gabbro is probably Jurassic in age. The sills form a structural basin which contains remnants of sedimentary country rocks, some of which are as young as Permian or Triassic according to pollen identification by R. A. Scott.

SOUTHERN ALASKA

Glaciers active along southern coast since Miocene time

An exceptionally long and complete record of Cenozoic glaciation is preserved in the Gulf of Alaska Tertiary province along the coast of southern Alaska. Seven sections of this sequence were measured in detail by George Plafker between Middleton Island and Icy Point to supplement earlier reconnaissance investigations by D. J. Miller and others. The fieldwork shows that the sequence, which contains distinctive marine conglomeratic mudstones and sandy mudstones that are interpreted as glacial debris, is at least 16,500 feet in aggregate thickness. Lithologically similar deposits of unconsolidated sandy mud and pebbly mud are now accumulating locally near tidal glaciers in southern Alaska. The fieldwork and studies of the marine molluscan faunas by F. S. MacNeil indicate that active tidal glaciers or an ice shelf were present along the coast intermittently during the middle and late Miocene (Astoria), and almost continuously throughout the Pliocene and early to middle Pleistocene. Mollusks of definite Pleistocene age (probably pre-Yarmouth) were identified only in collections on the Middleton Islands, from the upper part of the 3,875-foot-thick section, the top of which is not exposed. Younger deposits of Pleistocene age have not been found in outcrop, but probably are present in the subsurface and offshore on the continental shelf.

Mesozoic stratigraphy of Matanuska area

A stratigraphic reconnaissance by Arthur Grantz of upper Mesozoic rocks in the Kotsina-Kuskalana area, supplemented by isotopic age data by M. A. Lanphere and study of fossil mollusk collections by D. L. Jones and R. W. Imlay, indicated that the Kotsina Conglomerate is Jurassic (not Cretaceous) and showed that this conglomerate and sedimentary rocks of Late Jurassic (Callovian?) and Early Cretaceous (Hauterivian and Albian) ages are locally present between Kotsina River and Mount Drum. The Hauterivian beds include a nearshore facies to the north which is lithologically very similar to the Nelchina Limestone and to an offshore facies to the south which has not been previously reported from beds of this age in the Matanuska geosyncline.

New and revised paleontologic work by D. L. Jones and additional field stratigraphic studies by Arthur Grantz have shown that dissimilar facies in the lower part of the Matanuska Formation (Late Cretaceous) in the southern part of the Nelchina area are closely juxtaposed. The juxtaposition is apparently produced by the presence of abrupt facies changes in the formation. The abrupt facies changes may have been accentuated by a fault or fault system with a significant lateral component of displacement.

Tertiary stratigraphy of Cook Inlet region

Paleontologic and stratigraphic studies by J. A. Wolfe, D. M. Hopkins, and E. B. Leopold in the Cook Inlet region suggest that the ages of some early Tertiary units will require revision. A threefold zonation of the Kenai Formation has been established on the basis of fossil floras, and the pollen assemblages of each zone have been characterized, permitting refined local correlations which should assist the active petroleum exploration presently in progress in the Cook Inlet area. The threefold zonation established in the Kenai Formation can be applied to Miocene and Pliocene rocks elsewhere in Alaska, and this assists in making regional correlations and in analyzing the late Tertiary tectonic history of Alaska. The fossil floras obtained from the Kenai Formation and from other parts of Alaska provide a record of deteriorating climate in Alaska and illuminate the evolution of the modern taiga and tundra vegetation from the mixed hardwood forest that clothed Alaska in early Miocene times.

Copper ore controls in MacLaren River area

The Kathleen-Margaret (MacLaren River) copper prospect, examined by E. M. MacKevett, Jr. (p. C117–C120) explores north-striking quartz veins north of an east-striking fault zone. Only one of the quartz veins is large enough and rich enough to have encouraged much exploration. This exploration showed that the copper values, which are contained chiefly in chalcopyrite and bornite, diminish in the vein northward from the intersection between the vein and the fault zone.

SOUTHEASTERN ALASKA

K–Ar ages indicate probable early Paleozoic intrusive

Geochronologic studies in Alaska by M. A. Lanphere and G. D. Eberlein provide the first direct evidence suggesting emplacement of early Paleozoic intrusive granitic rocks along the western margin of the North American continent. K–Ar ages on hornblende concentrates from quartz diorite and from quartz monzonite near Bokan Mountain, Prince of Wales Island, are 430 million years and 445 m.y., respectively. Biotite from the quartz monzonite gave a lower K–Ar age of 370 m.y. The Bokan Mountain and Tenakee intrusive rocks therefore probably are among those that contributed granitic debris to the middle Paleozoic conglomerate units throughout southeastern Alaska.

K–Ar ages of minerals from syenite complex

Hornblende from syenite at Tenakee on Chicagof Island gave a K–Ar age of 405 million years, and coexisting hornblende and biotite from the same syenite complex at Point Hayes yielded ages of 230 and 113 m.y., respectively.

Abrupt facies changes in Alexander Archipelago area

Striking facies changes in Triassic, Permian, Carboniferous, and Devonian sedimentary rocks have been mapped and studied by L. J. P. Muffler for a distance of more than 6 miles across the northwest-trending structural grain in the area between Kuiu and Kupreanof Islands. Detailed stratigraphic studies exclude the possibility of appreciable tectonic transport during the period of deformation (late Cretaceous or Paleocene) and suggest further that both Triassic and Paleozoic sedimentation took place in troughs parallel to the present structural grain.

Two generations of folding at Cape Fanshaw

On the mainland northeast of Kupreanof Island, in the vicinity of Cape Fanshaw, two generations of folds were mapped by L. J. P. Muffler. Cleavage related to isoclinal first folds in Jurassic and Cretaceous graywacke and argillite is deformed into a steeply plunging second fold of large amplitude. The two inferred episodes of folding are correlated with the first and second episodes of Late Cretaceous or Paleocene folding that occurred in the Pybus-Gambier area on Admiralty Island, 20 miles to the west.

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PUERTO RICO

Provisional geologic map

A geologic map (Briggs, 1–64) of Puerto Rico and adjacent islands shows that the central core of Puerto Rico consists of Cretaceous and lower Tertiary volcanic and sedimentary rocks cut by hundreds of faults and intruded by serpentine of Cretaceous(?) age and dioritic intrusive rocks of Cretaceous and early Tertiary age. On the northern and southern coasts these older rocks are overlain by several thousand feet of generally calcareous sedimentary rocks that dip gently seaward and by many kinds of surficial deposits mainly of Quaternary age.

Deformation along south coast

Conglomerate on Isla Caja de Muertos, off the south coast of Puerto Rico, about 10 miles southeast of Ponce, collected by P. H. Mattson contains Eocene larger Foraminifera in pebbles and Oligocene large Foraminifera in the matrix, according to K. N. Sachs, Jr. The conglomerate is probably correlative with some of the Oligocene strata in the coastal plain of southern Puerto Rico. It dips about 35° SE. and is overlain unconformably by subhorizontal limestone also believed to be equivalent to a part of the Oligocene and Miocene coastal-plain sequence. This relation indicates that deformation occurred in this area in Oligocene or possibly Miocene time.

Late Cretaceous laumontitization

As a part of his study of the general geology of the Coamo area in south-central Puerto Rico, Lynn Glover is investigating the distribution, genesis, and time of formation of zeolite-bearing assemblages in the Upper Cretaceous and lower Tertiary volcaniclastic rocks. At present the zeolites clinoptilolite, stilbite, analcime, and laumontite have been identified. Laumonite is particularly abundant in the higher Upper Cretaceous rocks, where it formed most readily in the permeable plagioclase-rich crystal tuffs of the Cariblanco Formation. In the presence of water and dissolved silica, plagioclase broke down to form albite and laumonite. The reaction occurred after considerable burial because laumontite also fills cracks developed during load crushing of such nonreactive minerals as hornblende. The generation of laumontite-bearing assemblages was a regional phenomenon and in places encroached upon the earlier prehnite and epidote of contact zones around small intrusives. The intrusives have been dated geologically, and this allows some limits to be put on the age of laumontitization. On this basis the laumontite seems to be latest Cretaceous (Maestrichtian) or younger.

Gravity survey of south coast basin

A detailed gravity survey of a potentially petroliferous Tertiary sedimentary basin on the south coast of Puerto Rico indicated minimum simple Bouguer anomaly values at Punta Cabullón in the Playa de Ponce quadrangle. The gravity gradients indicate that even lower values must exist offshore to the south of this area. These lower values probably indicate the location of the deepest portion of the sedimentary basin.

Karst phenomena

Lithologic control in the development of karst topography is well illustrated in the geologic map of the Camuy quadrangle by W. H. Monroe (1–63). Deep steep-sided sinks are confined to the outcrop belt of the Aguada Limestone, which consists of alternating beds of hard and soft limestone. Mogotes or steep-sided subconical "haystack" hills are restricted to the outcrop belt of the Aymamón Limestone, which consists of nearly pure compact chalk that is dissolved and reprecipitated at the surface into hard dense limestone. Hard ferruginous limestone of the Camuy Formation forms long smooth ridges.

Several series of long, narrow, parallel solution trenches have been discovered in north-central Puerto Rico affecting thin-bedded somewhat impure limestone. These trenches, named zanjones (Spanish zanjón= large drainage trench) by W. H. Monroe (p. B126–B129) seem to represent a persistant deepening and widening of joint cracks by action of acidic waters derived largely from decay of forest vegetation. In contrast to zanjones, the slightly similar karren or lapiés form only on bare, generally pure limestone and are usually more closely spaced. The somewhat similar cutters of Tennessee form only under soil, whereas zanjones may form under a thin forest litter.

ANTARTICA

The U.S. Geological Survey is cooperating with the National Science Foundation and its U.S. Antarctic Research Program (USARP) in carrying out continuing geologic studies in Antarctica. Where feasible, reconnaissance geologic mapping is an integral part of the investigations. Topographic and planimetric base maps are compiled by the Topographic Division (see "Mapping in Antarctica"). Logistical support for the Antarctic field projects is provided by the U.S. Navy Operation Deep Freeze.

Geology of central Pensacola Mountains

The Pensacola Mountains (fig. 7) are a 250- by 50-mile north-northeast-trending mountain region comprised of three main mountain groups, along the southeast margin of the Filchner Ice Shelf. Geologic mapping of the central mountain group, the Neptune Range, by D. L. Schmidt, P. L. Williams, W. H. Nelson, and J. R. Ege in the austral summer of 1963–64 has demonstrated a lengthy and complex history of sedimentation, volcanism, igneous intrusion, and deformation probably in early Paleozoic and earlier time. Three major folded sequences, each separated by angular unconformities, in the central and the southern Pensacola Mountains (the latter studied in the 1962–63 field season) have a total stratigraphic thickness of at least several tens of thousands of feet.

The lowest unit, the Patuxent Formation, believed to be of Precambrian age, consists of graywacke and slate, with locally abundant flows of basalt that are in part pillow bearing. Diabase sills and felsitic plugs intrude this unit in a few places.

The middle unit consists of bedded limestone, rhyolite flows, shallow-water shale and siltstone, and volcanic sandstone and conglomerate. The rocks have been intruded by hypabyssal sills and irregular crosscutting bodies of rhyolite, and are folded in open sinuous folds with moderately steep to overturned limbs. The limestone is fossiliferous and the unit is probably of early Paleozoic age.

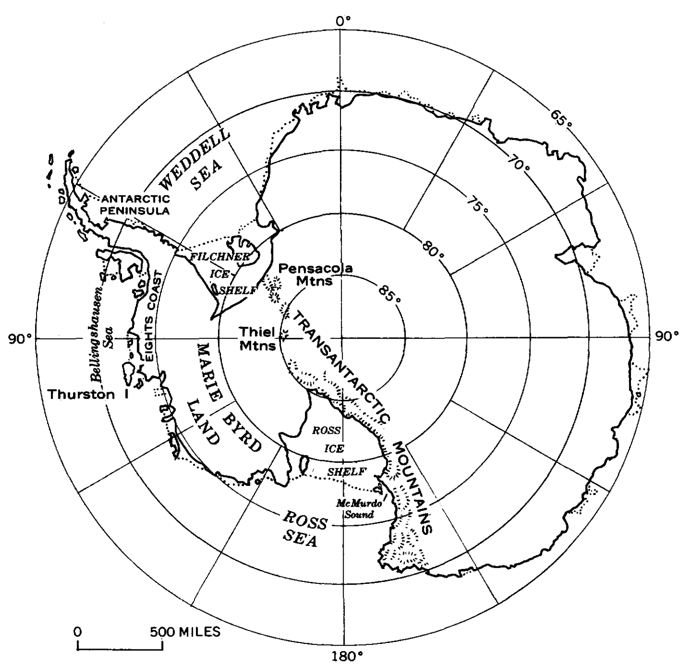

FIGURE 7.—Index map of Antarctica.

The upper unit consists of orogenic conglomerate, red calcareous sandstone, and conglomerate with clasts of mostly volcanic materials, red quartzose siltstone and sandstone, tan quartzose sandstone, and massive black siltstone containing scattered pebbles and cobbles. These rocks are folded in broad, sinuous folds which locally have steep or slightly overturned limbs. Fossils have not been found in the unit.

Stratigraphically above the three sequences of folded rocks are nearly flat-lying quartzose siltstones and sandstones, as well as quartzites, that occur in the southernmost mountain group of the Pensacola Mountains and that appear very similar to the Beacon sedimentary rocks in other parts of the Transantarctic Mountains, according to D. L. Schmidt, A. B. Ford, J. H. Dover, and R. D. Brown (1–63). Devonian and Permian plant remains from carbonaceous interbeds have been identified by J. M. Schopf at the U.S. Geological Survey coal laboratory in Columbus, Ohio. The Permian flora has typical Gondwana characteristics. Diabase sills, probably of Jurassic age, occur in the upper Paleozoic sequence.

Pensacola Mountains meteorite find

A nickle-iron meteorite, the fourth meteorite yet to be discovered in Antarctica, was found by J. R. Heiser and D. C. Barnett of the Topographic Division in the central part of the Neptune Range (lat 83°15′ S., long 55° W.) on February 7, 1964. The meteorite, weighing 2.4 pounds and measuring 4 by 3 by 2 inches, was found on a rock outcrop about 100 feet above the ice base of a nunatak. Evidently, it is a resistite which had been glacially transported.

Glaciology of central and southern Pensacola Mountains

The mean annual air temperature in the vicinity of the Geological Survey camp (lat 83°36′ S., long 57°15′ W.) in the Neptune Range was determined by W. W. Boyd, Jr., to be -25.8 ± 0.2°C, based on firm temperature measurements in an 11-meter-deep bore hole. Stratigraphic studies and firn density measurements in several pits indicate an average annual accumulation over a 16-year period of 8 centimeters of equivalent water. Almost 80 percent of the yearly accumulation appears to be during winter, and accompanied by very little wind. Four sets of surveyed stake lines in the Neptune Range provided bases for thickness profiles by gravimetry and for accumulation and ice-movement measurements.

In the Patuxent Mountains (lat 84°45′ S., long 63° 59′ W.), the southernmost one-third of the Pensacola Mountains, movement of local ice ranges between about 7 meters per year in a large central basin to about 15 m per year in a large glacier that enters the central basin from the east. Annual accumulation near the center of the basin ranges from 10 to 12 centimeters of equivalent water.

Geology of Thiel Mountains

Continued petrographic studies of cordierite-bearing hypersthene-quartz monzonite porphyry point to an origin of the porphyry, according to A. B. Ford (1–63), by the nearly complete melting of preexisting charnockite-like rocks such as those found throughout the shield region of East Antarctica. Numerous small lithic inclusions of hypersthene- and cordierite-bearing granulites scattered throughout the sill-like body of porphyry may be incompletely melted relicts of parental matter. Large corroded insets of cordierite and hypersthene in the porphyry, according to this interpretation, may be xenocrysts. Similar igneous rocks are not known to exist elsewhere in the Transantarctic Mountains. Stock-like or batholithic granitic bodies intrude the porphyry at several places and may be related to early Paleozoic plutonic activity that was widespread in the Transantarctic Mountains.

Age of intrusive rocks of Thiel Mountains

A late Precambrian to early Paleozoic time of formation of the igneous rock suites is indicated by radiometric zircon age studies by T. W. Stern, Harold Westley, I. H. Barlow, and C. S. Annell; by biotite age studies by H. H. Thomas, R. F. Marvin, Paul Elmore, and Hezekiah Smith; and by potassium feldspar and whole-rock age studies by C. E. Hedge and F. C. Walthall. A lead-alpha zircon age of 670±50 million years supports previously reported zircon dates of the quartz monzonite porphyry that average about 600 m.y. Biotite-bearing granitic rocks that intrude the porphyry yield mostly early Paleozoic radioactivity ages. Four K-Ar biotite ages of the intrusive rocks range from 484 to 511 m.y. Lead-alpha zircon ages of the granitic rocks are somewhat older, ranging from about 470 to 720 m.y. The early Paleozoic ages are in close agreement with most other reported ages of basement rocks elsewhere in the Transantarctic Mountains, according to J. M. Aaron and A. B. Ford (1–64).

Geologic reconnaissance of Eights Coast

Zircon from a sample of quartz diorite collected by A. A. Drake, Jr., from the Eights Coast region was found by T. W. Stern and H. Westley to have a lead-alpha age of 150±20 million years. This middle Mesozoic age, according to Drake (Chapter D) confirms the previous thought that the batholithic rocks of Eights Coast and Thurston Island are older than the plutonic rocks of Andean (Cretaceous to early Tertiary) age from the Antarctic Peninsula.

Biotite separated from the same sample was found by H. H. Thomas, R. F. Marvin, P. Elmore, and H. Smith to have a K–Ar age of 97±5 million years. This age may reflect a later orogenic event perhaps associated with younger plutonic rocks that are known to intrude the quartz diorite. The younger rocks are characterized by presence of myrmekite and resemble plutonic rocks of Andean age from the Antarctic Peninsula. The biotite age is in harmony with the suggestion that Andean plutonic activity may have extended to the Eights Coast region.

Antarctic paleobotany

It is becoming evident, according to J. M. Schopf (1–64), that the dominant glossopterid vegetation in Antarctica was arborescent, seasonally deciduous, and native to a temperate climate with favorable conditions for growth.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

For more than 20 years the U.S. Geological Survey has provided technical assistance to newly developing nations in geology, hydrology, and related sciences, under the auspices of the U.S. Agency for International Development and other national and international agencies. This assistance has been directed toward the appraisal of mineral and water resources and the establishment of cadres of experienced earth scientists in the developing countries. As a result of this coordinated assistance, vigorous national geological and hydrological agencies have been established in Afghanistan, Bolivia, Chile, Indonesia, Iran, Nepal, Pakistan, Philippines, Thailand, and Turkey; earth-science programs have been strengthened in Brazil, Ghana, Jordan, Korea, Liberia, Nigeria, Taiwan, Tunisia, and Sudan, and national geological maps or summary resources reports have been issued in Ecuador, Libya, Peru, and Saudi Arabia. In two decades of technical assistance, the U.S. Geological Survey has sent 485 members of its staff on investigations and training assignments in 68 countries and has provided specialized training in the United States for 731 scientists from 68 nations.

At the request of other governments, 124 specialists from the U.S. Geological Survey were assigned to 25 countries during fiscal year 1964, and geologists and engineers were brought to the United States for advanced academic or on-the-job training. The accompanying table (p. A124) summarizes the type of assistance given to each country by the Geological Survey during the year.

AFGHANISTAN

Surface-water studies in Helmand River basin

A compilation of streamflow, meteorologic, and sediment data for the Helmand River basin was released in early 1964. This report, prepared by R. H. Brigham, covers the 10-year period prior to 1960.

BRAZIL

Mineral deposits in Minas Gerais

From 1947 to 1962, field studies were carried on jointly by the Brazilian Departamento Nacional da Produção Mineral and the U.S. Geological Survey in the Quadrilátero Ferrífero, an area of about 7,000 square kilometers containing exceptionally large reserves of iron ore. This region has already produced mineral products valued at some $1½ billion and will probably surpass this past production in years to come. During fiscal year 1964, a Geological Survey Professional Paper chapter (Pomerene, 1–64) was issued covering three quadrangles in the north-central part of the Quadrilátero Ferrífero, an area containing estimated reserves of high-grade hematite ore (66+percent iron) totalling more than 570 million tons and extending to a depth of 50 meters below lowest exposure. The hematite ore bodies are regarded as replacement deposits formed by either hypogene solutions or circulating ground water, without apparent structural control. Three other papers were published in professional journals, including one on caves in canga (ferruginous breccia or conglomerate) found on dolomitic itabirite;[48] one on leucophosphite, an ammonium iron phosphate mineral caused by reaction of bat droppings with iron-formation (Simmons, 1–64); and one on the origin of high-grade hematite ore (Dorr, 1–64).

Amazon flow measured for first time

The first actual measurements of the flow of the Amazon River were made by a U.S. Geological Survey team consisting of R. E. Oltman (1–64), L. C. Davis, F. C. Ames, and G. R. Staeffler, in collaboration with the University of Brazil and the Brazilian Navy. Flow measurements at Obidos (above tidewater), made at high stage in July 1963, and at low stage in November 1963, indicated an average flow of 6.6 million cubic feet per second. Based on these measurements and an analysis of the hydrology of the Amazon basin flow at Obidos, the average outflow of the Amazon to the Atlantic was computed to be about 7.5 million cfs. Previous estimates have generally ranged from 3 to 5 million cfs. A 19-year record of river stage at Obidos together with the flow measurements formed the basis for rough estimates of maximum flow of 8½ million cfs and minimum

[48] G. C. Simmons, 1963, Canga caves of the Quadrilátero Ferrífero, Minas Gerais, Brazil: Nat. Speleological Soc., Bull., v. 25, pt. 2, p. 66–72.

Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1964

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Latin America					
Bolivia	2	Geologist	A	None	
Brazil	4	do	A, C, D	2	General geology.
	2	Cartographer		2	Economic geology.
	1	Topographic engineer		1	Ground-water hydrology.
	4	Hydrogeologist		1	Geochemistry and analytical chemistry.
	3	Hydraulic engineer (SW)		2	Stratigraphy and sedimentation.
				1	Paleontology.
				1	Photogeology.
Chile	2	Geologist	A	1	Engineering geology.
				1	Ground-water hydrology.
				1	Surface-water hydrology.
				1	Petrology and mineralogy.
				1	Stratigraphy and sedimentation.
Colombia	1	do	A	1	General geology.
				1	Photogeology.
Costa Rica	2	do	B	None	
	2	Geophysicist			
Ecuador	None			1	Surface-water hydrology.
Panama	None			1	General geology.
Peru	1	Geologist	C	None	
Africa					
Congo	None			2	Surface-water hydrology.
Dahomey	2	Geologist	B	None	
Egypt	3	Hydraulic engineer (GW)	A	2	Ground-water hydrology.
	1	Hydrogeologist		1	Quality of water.
	1	Publications specialist			
	1	Topographic engineer			
	1	Mathematician			
	1	Electronics specialist			
	1	Hydrochemist			
	1	Corrosion specialist			
Ghana	1	Hydrogeologist	B	None	
Liberia	2	Geologist	A	1	Surface-water hydrology.
				2	Exploration.
Libya	1	Hydrogeologist	B	1	Ground-water hydrology.
Morocco	None			1	Mining geology.
Nigeria	5	Hydrogeologist	A	None	
	2	Hydraulic engineer (SW)			
Sierra Leone	None			1	Economic geology.
				1	Geophysics.
Sudan	1	Hydrogeologist	B	2	Photogrammetry and surveying.
				2	Publications.
				1	Administration and supervision.

Footnote at end of table.

Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1964—Continued

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Tunisia	1 1	Hydraulic engineer (GW) Hydrogeologist	B		
Great Britain					
	None			1	Surface-water hydrology.
Near East-South Asia					
Afghanistan	2	Hydraulic engineer (SW)		3 1 1	Ground-water hydrology. Surface-water hydrology. Photogrammetry and surveying.
Ceylon	None			1	Economic geology
India	None			3 1	Do. Engineering geology.
Iran	1	Hydraulic engineer (SW)	A		
Iraq	None			1 1	General geology. Geochemistry and analytical chemistry.
Israel	1 1	Hydrogeochemist Hydrogeologist	B	1	Ground-water hydrology.
Jordan	None			2 1 2	Do. Surface-water hydrology. Exploration.
Nepal	1 1	Hydraulic engineer (SW) Sediment specialist	B	1	Surface-water hydrology.
Pakistan	15 1 1 2 2 1 1 1 1 1 5 1	Geologist Geophysicist Geochemist Photogrammetrist Cartographer Photographer Electronics specialist Publications specialist Driller Program assistant Hydrogeologist Corrosion specialist	A	1 2 5 3 2 1 2	General geology. Economic geology. Ground-water geology. Petrology and mineralogy. Geochemistry and analytical chemistry. Paleontology. Administration and supervision.
Saudi Arabia	8 2 2 1 1 1 1 2	Geologist Geochemist Geophysicist Chemist Geodesist Photogrammetrist Topographic engineer Program assistant	A	1	Administrative and supervision.
Syria	None			1	Ground-water hydrology.
Turkey	3 1 1 1 1	Geologist Photographer Hydrogeologist Geophysicist Hydraulic engineer (GW)	C	1 6 1 1 4	Engineering geology. Ground-water hydrology. Geophysics. Photogrammetry and surveying. Administration and supervision.

Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1964—Continued

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Far East					
Indonesia	2	Geologist	B	2	General geology.
				1	Petrology and mineralogy.
				1	Geochemistry and analytical chemistry.
				1	Geophysics.
				1	Stratigraphy and sedimentation.
				1	Marine geology.
				1	Mining geology.
				1	Exploration.
				1	Publications.
Japan	None			2	Geochemistry and analytical chemistry.
Korea	None			2	Ground-water hydrology.
Philippines	2	Geologist	A	2	Engineering geology.
				2	Ground-water hydrology.
				1	Quality of water.
				1	Petroleum geology.
Republic of China	None			1	Ground-water hydrology.
Thailand	4	Geologist	A, B	2	Ground-water hydrology.
	1	Driller		1	Geochemistry and analytical chemistry.
Viet Nam	1	Hydrogeologist	B		

[1] A, Broad program of advisory help in institutional development and direct help in resources appraisal. B, Limited program of advisory help, training, and investigation in selected fields. C, Advisory help or consultation, with specific training or investigational activity. D, Geological education; assistance to universities.

flow of 2½ million cfs at Obidos. Even the minimum flow exceded the greatest known flood of the Mississippi, and the maximum was more than 3 times that of the Mississippi.

CHILE

Ground-water investigations

Hydrologic investigations in collaboration with the Instituto de Investigaciones Geológicas have pointed out new sources of ground water in water-short areas at the opposite ends of Chile. In northernmost Chile, W. W. Doyel (1–64) reports that an artesian aquifer underlying the coastal terrace along the Chile-Peru border offers good possibilities for additional water supply for the port city of Arica. In Tierra del Fuego in southernmost Chile, Doyel and Octavio Castillo U. (p. B169–B172) report that oil-test wells drilled in the early 1950's indicate that water suitable for industrial and domestic use occurs in two artesian aquifers of Tertiary age which underlie a large part of the Isla Grande de Tierra del Fuego. Exploration of this artesian water will help alleviate a shortage which is handicapping further economic development of the area.

COLOMBIA

Mineral exploration program

A new program to explore and appraise mineral resources, and to help strengthen the National Geological Service (NGS) in the Ministry of Mines and Petroleum, was started in March 1964 under the auspices of the Government of Colombia and the U.S. Agency for International Development.

COSTA RICA

Study of volcanic activity and related problems

The current eruption of Irazú volcano northeast of San José, Costa Rica, which began in March 1963, has resulted in loss of life, ash accumulations over an area of more than 1,200 square miles, and damage to land, communications, and water supply. At the request of the U.S. Agency for International Development and the Government of Costa Rica, preliminary examinations of the volcano were made by K. J. Murata in September 1963 and J. P. Eaton in January 1964. In April 1964, a longer range geological and geophysical study was started to determine the characteristics of recent volcanism, to evaluate the geological conditions that constitute immediate hazards, including potential landslides and mudflows, and to recommend measures to minimize the effects of future eruptions. As part of this study, a survey of heat radiation in the area around Irazú volcano was made by R. M. Moxham and S. J. Gawarecki in cooperation with the Institute of Science and Technology, University of Michigan. Other phases of the study will include mapping of surficial deposits and geological structures in and near the volcanic belt, installation of three seismic stations to monitor earthquake activity, and establishment of leveling stations on the side of the volcano to check ground movements. Information resulting from these activities is expected to provide data needed for urban protection and redevelopment as well as a better understanding of the eruptive habit of volcanoes in the circum-Pacific volcanic belt.

INDONESIA

Engineering geology in Tjimanuk River basin

Reed Anderson of the U.S. Geological Survey and personnel of the Indonesian Geological Survey are studying the Tjimanuk River basin in West Java to develop a master plan for irrigation, flood control, hydroelectric power, and conservation. Good dam sites are scarce along the Tjimanuk River because of: (1) the youthful stage of erosion, with resulting steep, narrow stream canyons in the region of Pleistocene and recent volcanic deposits along its upper reaches; and (2) subdued topography in the region underlain by Miocene and Pliocene sediments along the lower course of the river. The entire basin is seismically unstable, and active faults are common. One potential dam site investigated but subsequently rejected was found to be cut by 6 faults, no less than 4 of which appeared to have been active since 1955. Investigations have centered on the site for Sakarwangi Dam, which is tentatively planned as a rock-fill structure about 120 meters high, resting on Pleistocene volcanic breccia and tuff, with a storage capacity of approximately 650 million cubic meters.

Geologic map

As part of its assistance to the Government of Indonesia, the U.S. Geological Survey is printing a new geological map of Indonesia, which has been compiled by the Indonesian Geological Survey from all available sources. The map will serve as a reference in exploration and development of the nation's resources and as a basis for planning more detailed mapping of the country.

KOREA

Ground-water reconnaissance

W. W. Doyel and R. J. Dingman (chapter D), reporting on a ground-water reconnaissance of the Republic of Korea, conclude that large additional supplies of ground water, now virtually untapped, can be developed from alluvial fill in river valleys and from coastal deposits. Such development will be required to meet the demands of population increase and industrialization; the use of wells for supplemental irrigation will reduce damage to the rice crop from recurring droughts.

LIBYA

Geologic map

A new geological map of Libya compiled by L. C. Conant and G. H. Goudarzi (1–64) was officially presented to the Government of Libya on March 3, 1964, in ceremonies at the Ministry of Industry in Tripoli. Prepared under the auspices of the U.S. Agency for International Development and the Kingdom of Libya, with the cooperation of the Petroleum Commission and Petroleum Exploration Society of Libya, the map is at a scale of 1:2,000,000. It shows 46 sedimentary and igneous rock units representing all geologic periods except the Permian. In the south and west it reveals broad outcrops of Mesozoic rocks and narrow belts of Paleozoic rocks, separated by alluvial basins and deformed by southwest-trending folds and faults. In the north, Tertiary and Quaternary units are cut by subparallel northwest-trending faults, many of which have been active during the Quaternary.

PAKISTAN

Geologic map

An important objective of the Mineral Exploration and Development Program conducted jointly by the U.S. Geological Survey and the Geological Survey of Pakistan, under the auspices of the U.S. Agency for International Development and the Government of Pakistan, is to compile small-scale geologic, tectonic, and mineral-resources maps that will aid in the exploration and development of Pakistan's natural resources. The first of these maps, a new geological map of Pakistan at a scale of 1:2,000,000, has been compiled and is now being prepared under the direction of R. O. Jackson, J. T. Heare, and A. J. Freda for printing by the Survey of Pakistan press in Rawalpindi. An important by-product of this joint activity has been the compilation of a geographic base, the first available at this scale. The various segments of reproduction copy are being prepared jointly by the Geological Survey of Pakistan in Quetta and the U.S. Geological Survey in Washington.

Chromite studies, Hindubagh district

Concentric circular fractures observed on aerial photographs of the ultramafic intrusive at Hindubagh, West Pakistan, are being intensively studied by Roger Van Vloten, who believes that the structures may have been caused by upward-thrusting serpentine masses piercing the overlying dunite. Specific-gravity determinations of a large number of samples reveal that the centers of the structures consist of serpentine of low density. Gravimetric studies of one of these structures by geophysicists of the Geological Survey of Pakistan, under the guidance of W. J. Dempsey, show a positive anomaly of 2 milligals, suggesting a mass of chromite near the surface.

Paleozoic reef discovery in West Pakistan

Fossiliferous limestone mapped by K. W. Stauffer and personnel of the Geological Survey of Pakistan has been identified by Curt Teichert as a relief belt comprising the first Paleozoic reef facies discovered in Pakistan or India. The belt contains a number of reefs 300 feet thick, or more, which crop out along a narrow east-trending ridge rising as much as 250 feet above the surrounding plain, about 1½ miles north of Nowshera and about 25 miles east of Peshawar in the northern part of West Pakistan (lat 34° N., long 72° E.). The reef limestone contains tabular and spheroidal stromatoporoids, tabulate corals, rugose corals, brachiopods, gastropods, and large cephalopods. The age of the reef limestone is either Silurian or Devonian. Reef biotas of these two periods have many genera in common. All genera identified so far range through both periods or longer. The rugose coral, *Mucophyllum*, according to W. A. Oliver, Jr., is most characteristic of Silurian strata, although its range extends into the Lower and, possibly, Middle Devonian.

Fossil assemblages from some other limestones less than 30 miles away seem to be correlative with those of the Nowshera reef, especially those of the Kali limestone, which is found in the Mardan district and has reef characteristics. Previously some of these limestones had been assigned to the Precambrian; all others had been considered to be Carboniferous and Permian.

The presence of reefs associated with porous dolomite and fetid black limestones may be significant in the exploration for oil.

Structural studies in Hazara district

Geological mapping in the Hazara district of northern Pakistan by T. W. Offield, J. A. Calkins, and members of the Geological Survey of Pakistan has yielded detailed structural information for the large part of the apical area and western limb of the famous 180° "syntaxial bend" near the western end of the Himalayas. Analysis of the structural geometry by Offield indicates that this bend was formed by large-scale southward extension of rock masses on either side of an axial zone in which such movement was impeded. Folds were initially formed parallel with the principal direction of movement and were succeeded in a later phase by folds of a different type oriented perpendicular to the movement. Evidence presently available indicates that the horseshoe configuration of the "syntaxial bend" was produced by differential extension (flow) during a single orogenic event rather than by flexing of a line of preexistent structures.

Sor Range–Daghari coal field

A mapping and training program of the Geological Survey of Pakistan carried on between 1956 and 1963 under the guidance of J. A. Reinemund resulted in detailed mapping of Pakistan's most productive coal field, the Sor Range–Daghari field. The coal crops out in the mountains near Quetta for a distance of nearly 20 miles. Geological maps on a scale of 1:6,000 have already been supplied to many coal-mine operators for use in planning mine development; the maps provided guidance for driving two long adits that reached coal early in 1964 and are scheduled for production of 2,000 long tons per day. Total coal reserves in all categories in the Sor Range–Daghari field have been estimated at about 50 million long tons, about half of it presently classed as recoverable. The geological studies in this field have revealed a significant unconformity within the Eocene coal-bearing formation and a divergence between the trends of deformation in Quaternary strata and in older rocks.

Water-logging and salinity control in Punjab region

Currently a U.S. Geological Survey hydrologic team headed by M. J. Mundorff is evaluating the effectiveness of tubewell networks in two large salinity-control and reclamation projects located in Rechna and Chaj Doabs of the Punjab region. Since 1961, large-scale pumping from these wells has already lowered the water table an average of about 4 feet in the project areas. The lowering of the water table will enable large blocks of land, now out of production, to be reclaimed for agriculture.

PERU

Plans for central geological service

At the request of the Government of Peru and the U.S. Agency for International Development, G. E. Erickson studied the problems and requirements for establishing a central geological service in Peru. His report recommends establishing a geological agency with about 80 employees to undertake a national mapping and resources-appraisal program under a 10-year assistance plan.

SAUDI ARABIA

Mineral exploration project started

Under an agreement with the Kingdom of Saudi Arabia signed in September 1963, the U.S. Geological Survey has begun geological mapping and appraisal of mineral-resources possibilities in central and western Saudi Arabia. Sixteen members of the Survey, under the supervision of Glen Brown, have started geological, geophysical, geochemical, and topographical surveys, and are providing assistance to the Ministry of Petroleum and Mineral Resources in establishing facilities for geological and topographical work. Geochronology and photogrammetry laboratories are under construction in Jidda to support the surveys. Known mineral showings are to be evaluated with the help of geophysical exploration and drilling. Guidelines for future exploration are to be developed through the mapping of approximately 315,000 square miles in the Arabian shield.

Geologic maps issued

Twenty-one geological maps of Saudi Arabia on a scale of 1:500,000 prepared by the U.S. Geological Survey and the Arabian American Oil Co. under the auspices of the Ministry of Petroleum and Mineral Resources have now been issued, nine within the past year (R. A. Bramkamp, 1 to 4–63; G. F. Brown, 1 to 3–63; and L. F. Ramirez, 1, 2–63). In addition, separate geological and geographical maps of the entire country on a scale of 1:2,000,000 have also been published.

THAILAND

Mesozoic rocks of northeastern Thailand

A report compiled by D. E. Ward for publication by the Royal Thai Department of Mineral Resources describes the stratigraphy of the Khorat Group in northeastern Thailand. These Mesozoic sedimentary rocks are nonmarine and are more than 12,000 feet in aggregate thickness; thick but lenticular beds of rock salt and gypsum are present in two areas in the uppermost formation of the group.

Mineral exploration in northeastern Thailand

C. T. Pierson, H. S. Jacobson, and personnel of the Royal Thai Department of Mineral Resources are systematically investigating mineral showings in northeastern Thailand under the auspices of the United Nations Special Fund and the Governor of Thailand. Geological, geophysical, and geochemical surveys have revealed the presence of four previously unreported iron deposits, and drilling programs have been scheduled for two promising iron deposits and one base-metal deposit.

Geologic map of Phuket Island completed

C. L. Hummel, U.S. Geological Survey technical advisor, and Prachuab Phawandon' of the Royal Department of Mineral Resources have completed a map on a scale of 1:50,000 of the geology and mineral deposits of Phuket Island, South Thailand, and of adjacent parts of the mainland to the north. The map, in two sheets, Northern and Southern Phuket Island, is extensively annotated. Siltstones and shales of Cambrian age, making up the Phuket Series, are in part metamorphosed to mica schist along a northward-striking central belt. Granitic intrusives of Cretaceous age form the most widespread bedrock.

INVESTIGATIONS OF PRINCIPLES AND PROCESSES

A substantial part of the Geological Survey research program is primarily topical and involves the application of principles and analytical techniques largely developed in the laboratory to the elucidation of the evolution, composition, and structure of: (1) the earth as a whole, (2) its rocks and minerals, (3) its constituent elements, (4) its waters, and (5) its past and present living forms. The emphasis is upon quantitative measurements as a means of obtaining basic data having genetic significance. For the past several years the scope of the topical studies has been broadened to include investigations of the moon and of materials of extra terrestrial origin under sponsorship of the National Aeronautics and Space Agency.

The program of topical studies is, by its nature, long term, but it has produced important current benefits. For example, the program has played an integral part in setting up and operating a nationwide nuclear blast and earthquake detection system, together with the eruption warning system for the island of Hawaii. Studies of the stability relations and isotopic compositions of minerals have given insight into the ore-forming processes and have provided new guides for finding ore. Many new analytical techniques and methods of wide application, with the Geological Survey and without, have been developed in the fields of wet chemistry, emission spectroscopy, mineralogy, X-ray spectrometry, and the electron microprobe. Analytical services in these fields and in the fields of paleontology and geochronology are provided for the Geological Survey as a whole.

PALEONTOLOGY

The activities of Geological Survey paleontologists are divided between applied paleontology, a service summarized in numerous administrative reports on fossils submitted for examination by Survey and other geologists, and paleontologic research involving biostratigraphic, taxonomic, and ecologic studies. In more specific terms, paleontologic objectives can be grouped under four headings: (1) restudy of classic stratigraphic areas, (2) biostratigraphy, (3) evolution of major plant and animal groups, and (4) biologic oceanography and paleoecology.

CLASSIC AREAS

Much of the biostratigraphic framework on which general geologic and paleontologic conclusions depend was established 50–150 years ago. Many of the basic data have not been reviewed critically in the light of incurred knowledge of the present generation of geologists. Recent advances in paleontologic, stratigraphic and sedimentologic techniques require a reexamination of the fundamental framework. Studies are initiated as the opportunities arise.

Bryozoans and brachiopods in the Upper Ordovician of the Cincinnati region

In conjunction with the cooperative mapping program of the Kentucky Geological Survey and the U.S. Geological Survey, a restudy of the standard Upper Ordovician sequence in the Cincinnati region, Ohio, is underway. Among the early results of this program, bryozoan and brachiopod distributions have proven most useful. Preliminary studies of bryozoans from the Maysville area by O. L. Karklins indicate that two faunal breaks occur in beds of Maysville age and older. One is approximately the Eden-Maysville boundary, and the other is about at the top of the Fairview equivalent. In addition, Karklins' bryozoan studies have enabled him to subdivide the Ordovician and Silurian genus *Pachydictya* into three parts, on the basis of microstructure. These differences, contrary to published reports of homogeneous microstructure, may lead to stratigraphically useful groupings of species.

Statistical studies by R. J. Ross, Jr., of the Late Ordovician brachiopod *Platystrophia ponderosa* from beds of Maysville age in northern Kentucky indicate a consistent shape difference between two closely related forms that occur in beds previously assigned to the "Bellevue" and the "Mt. Auburn." Perhaps a stratigraphically useful split in this widely distributed species will be documented as more data are accumulated and analysed.

Silicified fossils from 29 samples collected by R. C. Greene and R. B. Neuman in the Valley View and adjacent quadrangles, Kentucky, have added significantly to our knowledge of brachiopods and other fossils in the Ordovician of Kentucky. Neuman's studies indicate that some genera are found in formations where they had not hitherto been known to occur, and that some newly differentiated species and genera of silicified brachiopods prove to be excellent guide fossils to several of the formations distinguished for mapping purposes.

Differences in wall structure of Bryozoa

From an investigation of the cryptostome Bryozoa fauna from the Decorah Shale at several localities in Minnesota, O. L. Karklins concluded that (1) study of the internal structure in *Stictopora* and *Pachydictya* species has resulted in a new interpretation of the wall structure which appears to be very promising in grouping of species and genera in the family Rhinidictyidae, and (2) a few species of *Stictopora* and *Pachydictya*, and probably the genus *Escharopora*, can be used for an improved zonation of the formation.

On the basis of a new interpretation of the dark lines crossing the exozone in thin sections showing the longitudinal and transverse views, it is concluded that the so-called inner walls are not formed in genus *Stictopora*. After reinterpreting the internal structure in genus *Pachydictya*, it is also concluded that genus *Pachydictya* consists of three, and possibly four, species groups whose geographic and stratigraphic distribution is not known at the present time.

Ostracodes in the Silurian and Devonian of central New York

More than twelve genera of ostracodes have been found by Jean Berdan in the Onondaga Limestone of central New York. Several of these have not previously been reported in beds older than Hamilton, and others have not been found in beds younger than the Camden Chert. *Favulella* is the only genus that appears to be restricted to the Onondaga and its equivalents. Although ostracodes have been described from the Onondaga equivalents in Pennsylvania, only five genera have been reported from the type Onondaga of New York.

Drepanellina clarki has been identified by Jean Berdan in collections from the Herkimer Sandstone near Utica, N.Y., made by D. H. Zenger, Pomona College. The Silurian *D. clarki* zone of Maryland has been correlated by Ulrich and others with the Rochester Shale of New York. Until now, however, no specimens of *Drepanellina* had been reported from New York State. Because the Herkimer Sandstone is the eastern equivalent of the Rochester Shale, according to Gillette,[49] the correlations of earlier workers are borne out.

Criteria for defining correlatives of the standard Mississippian series in the West

As a result of detailed studies in several areas, Mackenzie Gordon, Jr., Helen Duncan, W. J. Sando, and J. T. Dutro, Jr., have agreed on criteria for recognizing approximate correlatives of the standard Mississippian series in the West. The Kinderhook-Osage boundary is considered to be the base of the *Homalophyllites-Vesiculophyllum* coral zone (base of Sando's zone C_1), and the Meramec-Chester boundary is placed at the top of the *Faberophyllum* zone. The Osage-Meramec boundary is generally marked by the appearance of fasciculate lithostrotionoid corals (base of Sando's zone D). The top of the Mississippian is characterized by a change is brachiopod assemblages with *Diaphragmus* below and *Rugoclostus* above.

Mississippian brachiopods in the Great Basin

Study of Mississippian productoid brachiopods of the eastern part of the Great Basin (in Utah) by Mackenzie Gordon, Jr. (1–64), has resulted in the recognition of 10 distinct assemblages in time sequential order. Over 60 Mississippian species are recognized; approximately 20 percent of these have been described previously. The productoid brachiopod zones have been correlated in part with the goniatite zones studied earlier by Gordon and the coral zones studied by Helen Duncan. It is now possible to recognize in the Great Basin, with close approximation, the provincial series (Kinderhook, Osage, Meramec, and Chester) of the American midcontinent.

Goniatites in the Hale Formation in Arkansas

Mackenzie Gordon studied Carboniferous fossils at the Geological Survey of Great Britain and discussed stratigraphy with British colleagues. These discussions and a comparison of cephalopod specimens have shown that the early *Reticuloceras* zone (R_1) goniatites, long unrecognized in the United States, do occur in northern Arkansas in the Hale Formation, where four species can be referred to *Reticuloceras*. However, nothing in the Arkansas section appears to represent the discoidal late *Reticuloceras* (R_2) zone species. In the Bloyd Shale, which should be of R_2 age, there are species of the genus *Gastrioceras*, unrecorded in

[49] Tracey Gillette, 1947, The Clinton of western and central New York: New York State Mus. Bull. 341, 191 p.

the British R_2 zone, but represented in Brittany by as yet undescribed species.

The fauna of the Hale Formation occurs in the upper part of the Cane Hill Member and locally in the basal several feet of the Prairie Grove Member. The new Arkansas fauna, found in Washington County, contains elements representative of the lowermost part of the lower *Reticuloceras* (R_1) zone in the British Carboniferous section. Goniatites related to lower Reticuloceras (R_1) zone species likewise occur in the upper part of the Hale Formation. The *Homoceras* zone, as yet unidentified in the United States, may be represented by the lower part of the Cane Hill Member that has yielded no cephalopods. The Hale Formation thus appears to be equivalent stratigraphically to at least the upper part of the Sabden Group and Kinderscout Grit group of the Midland or Central region of England.

Mammalian faunal zones at Big Bone Lick State Park, Ky.

A team of eleven paleontologists, geologists, and field assistants representing the University of Nebraska, the U.S. Geological Survey, and the William Behringer Memorial Museum has completed the second season of a 4-year project of excavating late Pleistocene mammals at Big Bone Lick State Park, Ky. Large excavations have been dug in 2 of the 3 terraces at the site, and 3 faunal zones have been delineated, as follows:

Zone A: Deposited since the coming of the white man, as indicated by the presence of the European pig, *Sus scrofa*. Also contains *Canis* sp., *Bison bison*, *Bos taurus*, *Odecoileus virginianus*, and *Equus caballus*.

Zone B: Apparently represents a period before the coming of the white man, but still within the Christian era, as shown by the discovery of an ornamental pendant ascribed to the Adena Indian culture, dating from 1,500 to 2,000 years ago. Bones of the modern buffalo, *Bison bison*, are very abundant. Also present are musk ox, elk, deer, and, probably reworked from older beds, bones of elephants, giant bison (*B. antiquus*), and extinct horse (*Equus complicatus*).

Zone C: Contains an extinct late Pleistocene fauna, dated by the C^{14} method as 10,600±250 years before present. It includes *Mylodon* sp. (ground sloth), *Mammut americanus* (mastodon), *Bison antiquus*, *Cervalces scotti* (extinct "stag-moose"), *Rangifer* sp. (caribou), *Equus complicatus*, and *Mammuthus primigenius* (woolly mammoth). Most of these bones were found in a rust-colored iron-rich layer that probably is an old soil zone. A climatic contrast is presented by the woolly mammoth (cold climate) and the ground sloth (relatively warm climate), which were found at about the same level in the excavation and only about 20 feet apart. It appears that the woolly mammoth remains were buried in a stream channel cut into the deposit in which the ground sloth was found.

BIOSTRATIGRAPHY

Parts of the United States have had only the most general biostratigraphic reconnaissance. These areas offer a challenge to carry out pioneering stratigraphic and biologic studies that involve large-scale collecting programs, with localities carefully documented in terms of structural and stratigraphic position. Detailed descriptions of these fossils provide valuable new information on regional correlations, age relations, and geologic history.

Siberian and North American faunas in the Cambrian of Alaska

Two early Cambrian faunas from the Cambrian section in Alaska west of the point at which the Yukon River crosses the Canadian border are being studied by A. R. Palmer. One, from the lowest limestone member of early Cambrian age, includes trilobites entirely of Siberian aspect. The other, from an Early or early Middle Cambrian boulder in the conglomerate above the shale-sandstone section that includes the limestone, contains trilobites typical of the North American province. Middle Cambrian assemblages, including elements known in both the Asiatic and American provinces, will prove very useful for problems of regional correlation. Upper Cambrian assemblages are yet to be studied in detail.

Early Middle Devonian corals from east-central Alaska are reported by W. A. Oliver, Jr., to be related to previously described faunas from the Urals and adjacent parts of the U.S.S.R. The collections from the Charlie River quadrangle, submitted by Earl Brabb and Michael Churkin, contain species of *Spongophyllum*, *Xystriphyllum*, "*Fasciphyllum*," and "*Pachyfavosites*" that are conspecific or closely similar to Russian species.

Middle Pennsylvanian beds in northeastern Alaska

Recognition of *Pseudogastrioceras* (*Phaneroceras*) by Mackenzie Gordon, Jr., from a collection made by H. N. Reiser in the Table Mountain region in the eastern part of the Brooks Range, establishes firmly for the first time in northeastern Alaska the presence of beds of Middle Pennsylvanian (Atokan) age. Also recognized for the first time in Alaska is the discoidal nautiloid *Phacoceras* of Late Mississippian age, from specimens collected by I. L. Tailleur near the head of the Kukpuk River in the western part of the Brooks Range, Alaska.

Atlantic and Pacific trilobite faunas reflect "mirrored" environments

Silicified trilobites collected by R. J. Ross, Jr., and L. A. Wilson, in company with Jim McAllister, from the *Orthidiella* zone of the Pogonip Group in the Ryan quadrangle, California, are very similar to trilobites reported by H. B. Whittington from Lower Head, Newfoundland. The Newfoundland assemblage comes from a 200- × 600-foot "boulder" of white limestone. In a comparable stratigraphic position in southwestern Nevada are large white limestone bioherms described by Ross and Cornwall.[50] These occurrences add to growing evidence of a remarkable mirroring of environments on opposite sides of the continent in early Paleozoic time.

Upper Paleozoic corals of the Western States

W. J. Sando has completed a restudy of the type specimens of upper Paleozoic coral species described in the various reports of the Federal geological surveys of the Western United States made in the last century. The study is a necessary prerequisite for description of the rich western upper Paleozoic coral faunas, which are in dire need of investigation for purposes of stratigraphic correlation and paleoecologic analysis. The classification of the corals has changed so profoundly in the last 100 years that only 1 of the 12 species considered retains the same generic name under which it was originally described. Six of the species are retained as useful taxonomic concepts. Of the remaining six, one is considered as a junior subjective synonym, three are regarded as nomina dubia, and two are rejected as a nomina oblita.

Middle Triassic ostracodes from North America

Triassic fossils are of interest because the beginning of the Triassic marks the extinction of a great number of organisms on the generic and higher level at the end of the Paleozoic Era and is the first record in the Mesozoic Era. Recently, I. G. Sohn found marine Middle Triassic ostracodes in Israel. As a result of his preliminary note, he received a collection from Nevada containing the first identified Middle Triassic marine ostracodes from North America. In order to obtain comparative material from Europe, Sohn collected from Triassic sedimentary rocks in northeastern France and found there also hitherto unrecorded Middle Triassic ostracodes. Preliminary results of this study (chapter D) suggest that several of the ostracode genera considered to have become extinct at the end of the Paleozoic have species of Triassic age.

Upper Triassic ammonites from Oregon

Several successive upper Karnian and lower Norian (middle Upper Triassic) ammonite faunas have been identified by N. J. Silberling in collections submitted by Bruce Nolf from the northern Wallowa Mountains in northeastern Oregon. Nolf's field studies of the Wallowa batholith wallrocks are under the supervision of W. H. Taubeneck at Oregon State University. Of particular significance is the occurrence of the lower Norian *Mojsisovicsites*, *Malayites*, and *Himavatites* faunas which relate to the faunal sequence recognized in northeastern British Columbia.

New Oligocene Foraminifera from Guam

Ruth Todd's study of rich and well-preserved fauna of smaller Foraminifera from the Mahlac Member of the Alutom Formation of Guam shows the fauna to be unlike any so far known from the Pacific islands. It can be correlated, by means of its good assemblage of planktonic Foraminifera, with the *Globigerina sellii* zone of early Oligocene age in East Africa. In addition, many identical species (both planktonic and benthonic) indicate that it can be correlated approximately with the Vicksburg of the southeastern United States.

Cool-water molluscan fauna noted in North Carolina

The first occurrence of a Miocene, Calvert-type molluscan fauna south of northern Virginia is reported by T. G. Gibson. The fossils were collected from the Lee Creek phosphate pit of the Texas Gulf Sulphur Co. near Aurora, N.C., 110 feet below ground level; the fossiliferous bed does not crop out at the surface. This find establishes a Miocene cool-water fauna south of the Cape Hatteras axis, the present barrier between cool and subtropical faunas.

Smaller Foraminifera of Georgia

Investigations by S. M. Herrick (1–64) of smaller Foraminifera occurring in surface and subsurface de-

[50] R. J. Ross, Jr., and H. R. Cornwall, 1961, Bioherms in the upper part of the Pogonip in southern Nevada, *in* U.S. Geol. Survey Prof. Paper 424–B, p. B231–B233.

posits of coastal Georgia show that these fossils are of late Miocene age and are equivalent to similar microfaunas previously reported from the Duplin Formation of Florida and the Carolinas. Except for single species belonging to the genera *Archaias* and *Sorites*, occurring in the lower Miocene of Georgia (Tampa equivalent), these Foraminifera constitute the only microfossils so far reported from the Miocene deposits of Georgia.

Smaller Foraminifera occurring in the large oyster bed at Griffin Landing, Ga., are late Eocene in age and are definitely equivalent to the microfauna occurring at Shell Bluff, Ga., according to Herrick (p. C64–C65). These findings show the two faunas to be equivalent, and the Shell Bluff microfauna to be of late Eocene age.

Range of oreodonts extended south to Panama

Continued study of Miocene mammals of Panama by F. C. Whitmore, Jr., has established that, in addition to deerlike traguloids and rhinoceros, the fauna includes oreodonts. These primitive ruminants, the most numerous members of the population of the High Plains of North America from Oligocene to Piocene time, had not previously been known south of the Big Bend country of Texas. The range of these animals is thus extended southward about 2,000 miles. The Panama oreodont is a member of the subfamily Merycochoerinae and probably a member of the genus *Brachycrus*, a Miocene form.

Information now available on the Panama fauna and compilation of information concerning other finds of early Miocene mammals in North and South America make it possible to locate with greater accuracy than before the strait that once separated the continents. The strait ran north-south in what is now western Colombia, and probably coincided with the Bolivar geosyncline. The entire Isthmus of Panama was attached to North America during at least part of the Tertiary Period, although, being a tectonically active area, it could have been at times broken up into a chain of islands. There is no evidence that the isthmus was attached to South America at any time between the Paleocene and the middle Pliocene.

EVOLUTION

Biostratigraphy, geochronology, and stratigraphic correlation are only as good as our understanding of the geologic histories of fossil groups. The more we learn about the evolution of major groups as a function of time, the more reasonable and accurate a picture we can paint of the changing geologic landscapes.

Restudy of rugose coral *Billingsastraea*

In North America, the compound rugose coral *Billingsastraea* ranges from late Early Devonian (middle Coblenzian) to latest Middle Devonian (late Givetian); it is not known, definitely, outside of North America, although it may occur in Europe and Australia. W. A. Oliver's (3–64) recent paper indicates that the genus is composed of astraeioid, thamnostraeioid, and aphroid corals with disphyllid structure. The oldest known species, *B. affinis*, is redescribed.

Ancestry of primitive molluscoid fossils

Ellis Yochelson's research in primitive molluscoid fossils suggests that the poorly known Upper Cambrian genus *Matthevia* Walcott may be the representative of an extinct class of mollusks related to, but distinct from, the Amphineura or chitons.

Redefinition of pelecypod family Ambonychiidae

A detailed comparative morphological study of the early Paleozoic pelecypod family Ambonychiidae was carried out by John Pojeta, Jr. North American genera of the family are redefined and their known stratigraphic ranges are tabulated. In addition, the phylogenetic relations of the family are considered and their biostratigraphic significance analysed.

Study of evolution of brachiopod genus Composita

Development of the brachiopod genus *Composita* through geologic times from Late Devonian through Permian is the subject of a paper by R. S. Grinnel, Jr., Lamont Geological Observatory, and George W. Andrews (1–64). Forty-two species and varieties were accepted for the study; 9 others were considered doubtful; and 18 were rejected as obsolete. Morphologic intergradation among associated, synchronous forms was analysed with the aid of frequency polygons. Lack of clear separation of the associated species indicated their dominant intergradation. These forms, previously described qualitatively, are considered typological species.

Environment of Foraminifera family similar in U.S.S.R. and United States

Representatives of the subfamily Tournayellinae Dain, 1953, calcareous Foraminifera first described in the U.S.S.R., have been found recently by B. A. Skipp (1–64) in Kinderhook, Osage, and Meramec rocks of North America. They are associated with endothyrid Foraminifera and are common and zonally distinctive in most Cordilleran faunas studied, but are rare in the midcontinent region. No Tournayellinae have been recovered so far from Devonian or Chester rocks in the

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United States, although they are common in the Devonian of the U.S.S.R. The remarkable similarity between the tournayellid and endothyrid faunas of Mississippian age in the Cordilleran region and those of early Carboniferous age of the Urals suggests coeval development and like environments, possibly connecting sea ways.

Septaglomospiranella Lipina, 1955, is found in the Redwall Limestone, Arizona; the Leadville Limestone, Colorado; the Madison Limestone, Wyoming; the Shunda and Pekisko Formations, Alberta; and the Gilmore City Limestone, Iowa. *Septabrunsiina* Lipina, 1955, is recognized in the Redwall and Madison Limestones, and in the Livingstone and Mount Head Formations, Alberta. *Tournayella* Dain, 1953, and *Septatournayella* Lipina, 1955, are common in (1) the Redwall Limestone, (2) beds formerly assigned to the Brazer Limestone in southeastern Idaho and northern Utah, (3) parts of the White Knob Limestone of Idaho, and (4) the Mount Head Formation, Alberta. They are rare in the Arroyo Penasco Formation, New Mexico, and the Salem Limestone, Indiana.

Illustrated guide to upper Paleozoic floral zones of United States

C. B. Read and S. J. Mamay provided for the first time an illustrated guide to the upper Paleozoic floral zones of the United States. They recognize 14 floral zones extending from the Early Mississippian into the Permian. This report includes photographs of key assemblages for each zone, as well as discussions of floral provinces and correlations. Utility of the report is enhanced by an annotated glossary, compiled by Grace Keroher, of all the stratigraphic terms used in the text.

New data cast doubt on age of conodonts in the Cameroons

John Huddle reports that abundant conodonts in a well-dated Triassic collection made by I. G. Sohn at Makhtesh Ramon, Israel, are the same as those reported from the Cretaceous Mungo Chalk of the Cameroons, Africa. This find casts some doubt on the age of the Cameroons occurrences, which are the only recorded Cretaceous conodonts, and suggests that they might be reworked from older strata.

Evolution of two Upper Cretaceous mollusks

A study of the geologic history of the Upper Cretaceous cephalopod *Haresiceras*, by W. A. Cobban (1–64), outlines the phylogenetic development of the genus and suggests its origin. The older species of *Haresiceras* are stouter than the younger species and have less complex sutures. The older species have constrictions on the early juvenile whorls, arched to nearly flat venters, and ribbing differentiated into primaries and secondaries on the adult body chamber; later species lack constrictions, possess flat to slightly concave venters, and have ribbing tending to be of uniform strength on the adult body chamber. The older species of *Haresiceras* have suture pattern and rib type in common with *Desmoscaphites* and *Clioscaphites*. Cobban believes the origin of *Haresiceras* is to be found in the Santonian scaphites of the western interior.

W. A. Cobban's investigation of the Late Cretaceous marine pelecypod *Inoceramus? fibrosus* (Meek and Hayden) revealed that this "species" consists of an early form with weak radial and concentric folds, a later form (typical form) in which radial folds dominate over the concentric ones, a still later form in which radial and concentric sculpture is of about equal strength, and a final form in which the concentric sculpture dominates. These phylogenetic changes aid in correlating the uppermost part of the Pierre Shale with equivalent strata farther west.

Classification, evolution, and geologic use of shrews

Study of the fossil and living shrews of the world has been undertaken by C. A. Repenning in order to establish systematic groups within the family and to discover the phylogenetic history of these groups. Review of the shrews has shown that four subfamilies (two extinct) are clearly recognizable and that one of these can be broken further into three tribes. Rate and direction of evolution have varied greatly within these groups. Also, the shrews appear to be highly endemic mammals not only geographically limited in both fossil and living species but also tending to remain so throughout appreciable spans of their evolutionary histories. Therefore, their usefulness in stratigraphic correlation varies greatly with the particular lineage represented and with the detail of the known provincial history in any particular area. Nevertheless, with due respect for these qualifications, the shrews are useful in correlation on a continental scale and, to a more limited extent, are of value in intercontinental correlation of Oligocene and more recent terrestrial rocks.

Areal and stratigraphic range of Desmostylians

Desmostylians, marine mammals that inhabited the nearshore areas of the North Pacific Ocean during the later Tertiary, have been studied by W. D. Mitchell with

C. A. Repenning (2–63). The most common genus, *Desmostylus*, has been considered an index fossil for the middle Miocene "Temblor Stage" in the California area but actually has a range from the late Oligocene to the late Miocene, as this age is used with Pacific coast marine rocks. The genus has been found in association with primitive *Hipparion* and *Pliohippus* horses considered to be early Pliocene in North American usage of terrestrial mammalian ages. *Desmostylus* is circum-North Pacific and is known from California, Oregon, Washington, Kamchatka, Sakhalin, and Japan.

The related genus *Paleoparadoxia* is also circum-North Pacific and ranges in age from early to late Miocene (but also is associated with fossil horses, which are evidence of early Pliocene age in terrestrial mammalian usage). The rare genus *Cornwallius* is known only from the early Miocene and from the eastern side of the North Pacific.

Sirenians, introduced into the North Pacific from the Caribbean area, are first known from the late Miocene (but again associated with horses generally considered to be of early Pliocene age and are found with desmostylian remains (both *Desmostylus* and *Paleoparadoxia*). Unlike the desmostylians, the sirenians did not become extinct before the end of the Miocene, but have inhabited the North Pacific area until Recent time. The sequence of events and the presumed ecologic similarity suggests a causal relationship between the introduction of sirenians to the North Pacific and the extinction of the native desmostylians.

BIOLOGIC OCEANOGRAPHY AND PALEOECOLOGY

To better understand fossil assemblages in terms of inferred environments and, thereby, to reconstruct land and sea distributions during past epochs, we must examine present day interrelations between organisms and their environments. The findings below bear on the general subject of paleogeographic reconstructions.

Use of diatoms in correlation and paleoecology

Many areas of both California and the Great Basin contain diatom-bearing sediments which range in age from Late Cretaceous to Recent, according to K. E. Lohman. The diatom assemblages in these rocks contain both short-ranging species that are useful for stratigraphic correlation, and others, still represented in living assemblages elsewhere, that are useful for paleoecologic interpretations. Distinctive diatom assemblages are known from the Moreno Shale of Late Cretaceous and Paleocene(?) age and from many sedimentary formations in Eocene, Oligocene, Miocene, Pliocene, and Pleistocene rocks in California from the San Francisco Bay area southward. These assemblages from rocks of Cretaceous through Miocene age are virtually all marine. Pliocene rocks in different localities contain either marine or nonmarine diatom assemblages. Pleistocene assemblages are dominantly nonmarine. Extensive areas of Miocene, Pliocene, and Pleistocene sediments in Nevada and other parts of the Great Basin also contain distinctive nonmarine diatom assemblages. In that region, diatoms are often the only fossils present. Here also, the diatom can provide much needed paleoecological information, as the Cenozoic lake basins varied greatly in depth, temperature, salinity, pH, and other factors of paleoecological importance.

Ranges of certain early Tertiary plant genera extended

A number of petrified fruits and seeds, relatively uncommon plant fossils, were collected by R. A. Scott from a locality near Lander, Wyo. This occurrence was discovered by Richard Keefer and David Love. The fossils, of early Tertiary age, include several genera in common with the London Clay flora of England and the Clarno flora of Oregon. The Wyoming discovery establishes a wider and earlier distribution for certain paleotropical plant genera in North America than has previously been known.

Large Mesozoic oyster shows unusual distribution

N. F. Sohl, of the Geological Survey, and E. G. Kauffman, of the U.S. National Museum, have completed a report on two species of large oysters from the Gulf Coast and Caribbean area. One of these is the largest known ostreid from the Mesozoic of North America; the other (*Arctostrea aguilarae*) is the largest known species of its genus and shows an unusual distribution that transcends the boundaries between the Caribbean and the Gulf Coastal Plain faunal province of the Upper Cretaceous. It is found in Alabama, Mississippi, Texas, Mexico, and Cuba.

Nonmarine snails from the islands of the open Pacific

H. S. Ladd has identified two fresh-water snails (*Gyraulus* and *Neritilia?*) from the Lower Miocene of Bikini and a third genus (*Melanoides*) from the Neogene of Viti Levu, Fiji. Except for a single river snail (*Theodoxus*), previously described from Fiji by Ladd, these are the first nonmarine fossils from the islands of the open Pacific.

First definite nonmarine lower Paleozoic ostracodes in North America

Fresh- and brackish-water ostracodes provided by J. W. Wells and studied by Jean Berdan from Middle and Upper Devonian localities in New York State are believed to be the first definitely nonmarine lower Paleozoic ostracodes found in North America.

Cenozoic marine paleoecology of Pacific coast

Studies of marine mollusks, by W. O. Addicott, are helping to unravel the marine paleoecology of the Pacific coast during the late Cenozoic, and are providing correlation aids for strata containing such mollusks. A systematic review of the gastropod genus *Nassarius* indicates that fossil species of this genus, a characteristic element of late Cenozoic molluscan faunas of the Pacific coast, are particularly useful in stratigraphic correlation of marine Tertiary and Quaternary formations. The intricate sculpture of the nassariids permits an unusual refinement in the recognition of species, many of which have a relatively restricted stratigraphic range. The genus first appears in strata of early Miocene age in California, and by middle Miocene had diversified into three subgeneric groups that have continued into Recent time as the principal nassariid subgenera in the northeastern Pacific Ocean.

A previously unrecorded late Pleistocene invertebrate assemblage from near Point Dume, western Los Angeles County, Calif., contains a small element of warm-water mollusks that are now restricted to latitudes far to the south. Addicott notes that these species represent the most northerly occurrence of subtropical taxa in upper Pleistocene deposits of the Pacific Coast.

Addicott's work has also shown that a large and varied invertebrate fauna from the Kern River area, California, may well provide a standard of reference for the correlation of middle Miocene marine strata of the Pacific coast. In what is probably the largest known Miocene molluscan fauna from the Pacific coast, there are approximately 175 species of gastropods, about one-third of which are new and undescribed. Many of these species are closely related to modern gastropods living in the Panamic molluscan province of the tropical eastern Pacific Ocean.

MARINE GEOLOGY AND HYDROLOGY

Regional studies of the Atlantic continental shelf and adjacent coastal and marine areas are continuing (Emery and Schlee, 1-63), but emphasis is shifting from synthesis of existing information to collection and analyses of new data and mapping of offshore areas.

ATLANTIC CONTINENTAL SHELF AND SLOPE

Topography of the sea floor

The Geological Survey is collaborating with the Woods Hole Oceanographic Institution and the U.S. Bureau of Commercial Fisheries Woods Hole Laboratory in a 5-year reconnaissance investigation of the Atlantic continental shelf and slope, under the direction of K. O. Emery of the Institution. To provide a base map for these investigations, Elazar Uchupi of the Institution has contoured the shelf and slope at a scale of 1:1,000,000, with contour intervals of 20 meters on the shelf and 200 meters on the slope, using data from the U.S. Coast and Geodetic Survey, the Canadian Hydrographic Service, and the Woods Hole Oceanographic Institution. Richard Pratt, also of the Institution, has completed preparation of a bathymetric chart of adjacent deep sea areas at a scale of 1:5,000,000. These charts will be published by the Geological Survey.

Studies by Elezar Uchupi of the topography, subsurface structure, surficial sediments, and associated organic materials on the northern part of the shelf provide much new information about the development and history of the shelf. Topographically the area can be divided into seven distinct provinces: (1) Nova Scotia continental shelf—a series of basins and flat-topped banks; (2) Bay of Fundy—a shallow trough between Nova Scotia and New Brunswick; (3) Gulf of Maine—a rectangular basin with hummocky topography; (4) Georges Bank—a large shoal with northwest-southeast-trending sand ridges to the southeast of the Gulf of Maine; (5) Nantucket Shoals—a series of northeast-southwest-trending sand ridges on the shelf; (6) Continental shelf from Massachusetts to Delaware—a broad gently sloping plane with broad low swells that trend roughly east-west, lying south of New England; and (7) continental slope—a gently sloping plane cut by numerous jagged steep-walled submarine canyons.

Composition of the bottom sediments

J. C. Hathaway (1-63), Jobst Hülseman,[51] J. S. Schlee (3-63), and J. V. A. Trumbull (1-63) have found that variations in the composition and texture of bottom sediments can be related in large part to their

[51] Jobst Hülsemann, 1964, Organic constituents: Woods Hole Oceanog. Inst. Summary of Inv. Conducted 1963, ref. 64-12, Chemistry-geology, p. 90-92.

topographic setting and origins. For example, in the Gulf of Maine, currents sweeping elevated banks have produced deposits that have a relatively high content of quartz, feldspar, and rock fragments; sand fractions are characterized by poor sorting. In contrast, basins and swales generally have greater amounts of chlorite, mica, and biogenic contributions of foraminifers and spicules. Content of organic carbon, carbonate, and aminoid nitrogen is generally low in the Gulf; the organic carbon and aminoid nitrogen tend to be concentrated with the finer sediments of low areas, and the carbonate is concentrated where tests of foraminifers are common in basins or where relict shell debris is abundant on banks. In general, relict glacial sediments of the Gulf of Maine have wide distribution of grain sizes and are poorly sorted when compared to better sorting of typical sediments on the open shelf where reworking has winnowed the fine debris.

Much of the sand as far south as New Jersey is probably relict and was deposited during lowered sea levels of the Pleistocene. Trumbull has found that the relict nature of the grains and lowered sea levels are indicated by a high percentage of iron-stained grains, an abundance of rock fragments near the shelf break, and patchy coarsening of the sand near the outer part of the shelf. Isolated concentrations of glauconite on the suggest local erosion of exposed Tertiary rocks.

Foraminifera ratios as indicators of environment

On the basis of analyses of more than 500 samples from the Gulf of Maine, Georges Bank, and the Cape Cod area, T. G. Gibson has been able to demonstrate distinct differences in formaniferal faunas of areas to the north and south of the Cape Cod-Georges Bank area. The fauna to the north has a subarctic origin and is related to fauna of Labrador and Greenland. The fauna to the south is temperate or subtropical in character, depending on the area's proximity to the Gulf Stream. Both benthonic and planktonic Foraminifera show the provincial distribution, although some southern Gulf Stream planktonic forms are dispersed into the Gulf of Maine. Within both faunal provinces, the Foraminifera have well-defined depth zonation. In general, the abundance of tests per gram of sample and the proportions of planktonic forms increase with increasing distance from shore in areas of uniform shelf conditions. In the Gulf of Maine where the topography is irregular and currents are variable, the proportions of benthonic to planktonic forms cannot be used to determine depth or distance from shore.

Structure of the Bay of Fundy interpreted from sonic profiles

Sonic profiling suggests to Elazar Uchupi (1–64) that (1) the Bay of Fundy is underlain by Triassic strata folded into a gentle syncline which has a thin cover of Pleistocene and post-Pleistocene deposits, (2) the Gulf of Maine is underlain by a Paleozoic(?) basement complex beneath Mesozoic to Recent sediments and glacial deposits averaging slightly less than 200 meters in thickness, and (3) Georges Bank is underlain by a thick sequence of Mesozoic and Cenozoic strata which dip very gently seaward and are covered by a thin blanket of Pleistocene sediments. Profiles of the open shelf and slope south of Martha's Vineyard show prograding upward and outward of the sediment layers.

Recovery of skeletal materials from plankton samples

During the spring of 1963, K. N. Sachs, Jr., of the Geological Survey, and Richard Cifelli, of the U.S. National Museum, took part in oceanographic investigations aboard the Woods Hole Oceanographic Institution research ship *Chain*. In attempting to recover radiolarians and Foraminifera from plankton samples, Sachs and Cifelli have developed a new technique for removal of soft-bodied phytoplanktons and zooplanktons which would otherwise either obscure or hopelessly entangle the tests and prevent their extraction. In the new technique, the sample is first washed with a hot 10-percent solution of hydrogen peroxide to remove as much protoplasm as possible. The resulting residue is filtered and washed with the aid of a Buchner funnel. The filter paper containing the residue is then dried, placed in a crucible, and heated in a furnace at 500°C until all cellulose and chitin have been volatilized, which generally takes about 2 hours. The technique leaves a concentrate of tests including radiolarians, foraminifers, pteropods, diatoms and other calcareous and siliceous shells and skeletal material. Examination of the delicate radiolarians and foraminiferal tests shows no appreciable damage to the tests and spines when compared with comparable material from untreated samples.

Whale bones indicate northward extent of Miocene

Elazar Uchupi, of the Woods Hole Oceanographic Institution, secured a collection of fragmentary fossil whale bones dredged by a fisherman in 50 to 70 meters of water on Georges Bank, off the Massachusetts coast. Included were a few fragments of cetotheres, primitive whalebone whales of the Miocene, which have been found on Martha's Vineyard Island and in the Chesapeake Group of Maryland and Virginia, as well as in the Miocene beds of Europe. This indicates that Miocene beds, probably a nearshore facies, extended north of Cape Cod, according to F. C. Whitmore, Jr.

GEOLOGIC STUDIES ON GUAM

Mariana Limestone contains ancient reef facies

The uplifted Mariana Limestone that forms the north half of the island of Guam contains facies of an ancient reef complex of Pliocene and Pleistocene age according to J. I. Tracey, Jr., S. O. Schlanger, J. T. Stark, D. B. Doan, and H. G. May. Coral and algae limestone of a reef facies near the present cliff-lined coast surrounds finer grained molluscan, coral, and foraminiferal limestone of lagoonal facies, and is bordered by outward-dipping detrital limestone of the outer slopes, similar to patterns of distribution found on living reefs. S. O. Schlanger recognizes diagnostic differences within thin sections of samples from the major facies of the reef complex; and he shows that comparable Miocene facies, preserved only in scattered outcrops, and Eocene facies, preserved only as fragments in pyroclastic deposits, existed and can be distinguished on Guam.

Algae in the Cenozoic limestones of Guam

J. H. Johnson (1–64) reports that he has found 82 species of calcareous algae belonging to 16 genera in the Cenozoic limestones of Guam. Of these, 1 genus and 20 species are new.

Mineral composition of lateritic soils as related to bedrock

In a study of the mineralogy of the lateritic soils of Guam, Dorothy Carroll and J. C. Hathaway (2–63) report (1) that the principal soil type on volcanic rocks contains halloysite, goethite, and a little gibbsite; (2) that soil on very pure limestone contains gibbsite, hematite, and a little halloysite; and (3) that soil on argillaceous limestone contains halloysite, goethite, and a little gibbsite. Lateritic soil on volcanic rocks has not been found higher than the inferred former extent of the Alifan Limestone of Miocene and Pliocene age, nor lower than the shoreline of the later Mariana sea, according to Tracey and others. Apparently the period of erosion following emergence of the Alifan Limestone during deposition of the Mariana Limestone was a time of lateritic weathering.

ESTUARY STUDY IN MARYLAND

Biologic study of the Patuxent River estuary

R. L. Cory has obtained records on the attachment organisms of the Patuxent River, which flows into Chesapeake Bay, for about 1½ years. At six sampling stations between Lower Marlboro and Solomons, Md., production of organic carbon varies considerably seasonally as well as from station to station. The period of greatest production extended from the beginning of May until the end of September. Highest values for this period were obtained at Lower Marlboro (672 grams per square meter), with continuously decreasing values downstream to Solomons (251 grams per square meter). Salinities at Lower Marlboro averaged about 6 parts per thousand, whereas average salinities at the Solomons station were about 18 ppt. More than 80 percent of the organic carbon obtained at Lower Marlboro formed during August and September and was attributable exclusively to barnacles and tube-building amphipods. The downstream stations exhibited a much larger variety of organisms and a longer period of sustained yield. The purpose of these studies is to monitor ecological changes that are anticipated with the introduction of heated water into the estuary.

The quality of attachment also varied considerably and usually consisted of only 1 or 2 dominant species from any 1-month period. Generally the following succession was noted at each of the stations: tube building amphibods, barnacles, bryozoans, tube worms, hydroids, sea squirts, and bryozoans and barnacles.

ASTROGEOLOGIC STUDIES

The Geological Survey is continuing its investigations in support of the space exploration program for the National Aeronautics and Space Administration. Basic investigations are being undertaken in four major fields: (1) Lunar geologic mapping by means of visual photographic and photometric studies with telescopes; (2) field and laboratory studies of terrestrial and experimental impact and cratering phenomena; (3) study of extraterrestrial materials of possible lunar origin; and (4) engineering studies designed to aid in conducting space missions.

LUNAR GEOLOGIC MAPPING

Geologic mapping of the earthward face of the Moon at a scale of 1:1,00,00 constitutes a major part of the Geological Survey's program. To date, mapping of more than 1 million square miles of the 3-million-square-mile area of the lunar equatorial belt has been completed. Geologic maps of the Kepler and Letronne quadrangles have been published in color, and preliminary geologic maps of the Copernicus, the Apennine Mountains (now called Montes Apenninus), the Aristarchus, the Timocharis, the Riphaeus, the Hevelius, and the Mare Humorum quadrangles have been completed and will be published in the Survey's quadrangle map series.

Lunar stratigraphy

Geologic mapping of the areas away from the central part of the Moon has led to the redefinition of the Procellarian System, represented by mare and dome material, as the Procellarum Group, a rock-stratigraphic unit, within the Archimedian Series of the Imbrian System. The Procellarum Group now consists of two fundamental units, the mare material and the dome material. This change was made necessary by recognition that complex time relations may exist between the Archimedian craters and mare material. As more geologic mapping on superior lunar photographs is completed, the lunar stratigraphic sections are being revised as new units are recognized and their extent and characteristics determined.

D. E. Wilhelms has recognized complex stratigraphy extending into the pre-Imbrian in his preliminary study of the Taruntius quadrangle. Of unusual interest is the material of the Palus Somni which is smooth but has higher albedo than mare material of the Procellarum Group and is partly ringed with groups of small craters along its margins. In addition, in the Procellarum Group there appear to be at least two mappable types of mare material, one type being characterized by a distinct waviness of the mare surface. On the nonwavy mare material, domes are probably more abundant than in any quadrangle studied so far. The majority of the domes have summit craters, but one has a small hill at its summit instead. Many craters on the maria seem to be alined, and there are also a number of rimless craters; Wilhelms suggests that many of these craters are of volcanic origin.

R. E. Eggleton [52] and H. J. Moore [52] found during study of the Riphaeus and Aristarchus quadrangles that the material interpreted to be ejecta, derived from the Imbrium Basin during its excavation, is widespread and has been designated the Fra Mauro Formation in the Apennian Series of Imbrian age. Another widespread unit which rests on the Fra Mauro Formation on the southern margin of the Imbrium Basin in the Montes Apenninus quadrangle has been designated the Appenine Bench Formation by R. J. Hackman.

E. C. Morris has traced the distribution of the Apennian Series in the western half of the Julius Caesar quadrangle. He finds that the Apennian Series has partly filled in the southeastern portion of the pre-Imbrian crater Julius Caesar more than the northwestern part, a relation that is interpreted to be the result of deposition of the Apennian Series from low-angle ballistic trajectories originating within the Imbrium Basin. Beneath the Appennian Series there may also be a deposit of material derived from the region of Mare Serenitatis which partly fills the southern portion of Julius Caesar more than the northern. The combined result is a depositional floor sloping slightly west of north.

Some of the oldest rock units were found by D. P. Elston [53] during mapping of the Colombo quadrangle. The oldest unit crops out in an arc of low hills of subdued relief peripheral to the northeast part of the Nectaris Basin and is informally named the Pyrenees Formation. It is interpreted to be the remnants of a regional blanket of material around the Nectaris Basin. The next younger unit comprises a distinctive group of crater deposits, characterized by the crater Gutenberg. The plan outline of this class of craters commonly is markedly polygonal, and crater floor material consists of jumbled blocks and slivers. The next younger deposit consists of a blanket of material that forms a plateau and highlands area in the northern part of the Colombo quadrangle. This material, informally named the Censorinus Formation, overlies, wholly or in part, several Gutenberg-type craters whose forms are still distinguishable through the blanket. The Censorinus Formation is interpreted to be part of a regional blanket of material derived from an event that occurred to the north. The youngest unit in the quadrangle forms a patchy veneer of smooth material on the Censorinus Formation, and may be equivalent to other smooth materials of regional extent found peripheral to the Serenitatis and Imbrium Basins.

New stratigraphic units of Imbrian–pre-Imbrian age were recognized by S. R. Titley [54] during study of the Humorum quadrangle. These are the Humorum Group composed of a rim and a bench unit and the Gas-

[52] U.S. Geological Survey, 1964, Astrogeologic studies annual progress report, August 25, 1962 to July 1, 1963: Part A.

[53] See footnote 52.

[54] See footnote 52.

sendi Group representing the class of craters later than the Humorum but flooded by mare material of the Procellarum Group of Imbrian age. The units of the Humorum Group are abundant peripheral to the Humorum Basin, a feature 300 kilometers in diameter.

Mapping of the Hevelius and Grimaldi quadrangles by J. F. McCauley [55] has led to investigation of the regional stratigraphic relations around Mare Orientale, a basin 320 kilometers in diameter, in the extreme west-central part of the visible lunar disk. Two new rock stratigraphic units of Archimedian age have been recognized in the region: (1) the Cordillera Group comprises the regional blanket that thins radially from the basin and contains two types of craters, and (2) the Cruger Group represents a class of post-Cordillera craters filled by mare material. Both units have proved useful in deciphering the structures and stratigraphy of the Hevelius quadrangle in the western part of the Moon.

Geologic mapping of the Timocharis quadrangle by M. H. Carr [56] has led to the recognition of features suggesting that an erosional process has occurred on the lunar surface. Study of the numerous secondary craters derived from formation of the Copernicus and Eratosthenes craters has shown that the Copernicus secondary craters have distinct and commonly cuspate outlines, and the Eratosthenes secondaries of equivalent size have indistinct, noncuspate outlines, rounded rim crests, and are less deep. Because Eratosthenes is demonstrably older than Copernicus, the Eratosthenes secondaries are thought to be a degraded form of Copernicus secondaries. Similar differences are found between the Rima La Hire I and Rima La Hire II craters. Rima La Hire II has a distinct outline and steep walls, whereas Rima La Hire I is indistinct, has rounded walls, and is very shallow. Hence, Rima La Hire I is thought to be an older degraded rill.

TERRESTRIAL AND EXPERIMENTAL IMPACT AND CRATERING PHENOMENA

Study of the structure, stratigraphy, and mineral composition of the lithologic units in and around natural and manmade terrestrial craters develops data that aid in determining the origin of such features and their relation to similar lunar features. The Geological Survey program of crater investigations is aimed at acquiring this information.

[55] See footnote 52, p. A141.
[56] See footnote 52, p. A141.

Stability and separation of impact polymorphs of SiO_2

B. J. Skinner and J. J. Fahey [57] have investigated the inversion rate of stishovite from Meteor Crater, Ariz., a very dense form of SiO_2 in sixfold coordination, which inverts to silica glass in fourfold coordination. The inversion rate, determined at ten temperatures between 300°C and 800°C and extrapolated to the time for total inversion of stishovite to silica glass, indicates the virtual impossibility that stishovite can be formed and preserved at the surface of the earth by any mechanism other than meteorite impact.

Coesite and stishovite, the high-pressure polymorphs of silica, were recovered by J. J. Fahey [58] from the shocked Coconino Sandstone at Meteor Crater by repeated treatments using hydrofluoric acid. The recovery of stishovite is quantitative because it is not attacked by hot concentrated hydrofluoric acid. Coesite is atacked by hydrofluoric acid, but much less readily than is quartz, and can be obtained by repeatedly leaching the host material with a 5-percent solution of hydrofluoric acid at 25°C. Colloidal and suspensoidal particles of coesite can then be separated from the residual quartz by repeated shaking and decantation in water.

TERRESTRIAL CRATERS AND STRUCTURES

Structure of the Sierra Madera west Texas

Detailed geologic mapping by E. M. Shoemaker and R. E. Eggleton [59] on the east flank of the nearly circular Sierra Madera disturbance in west Texas identified three previously unrecognized units: The Tessey Formation of Permian age, a thin section of probable Bissett Formation of Triassic age, and a thin unit of claystone, probably Triassic in age. The presence of these units eliminates the need for the existence of a significant angular unconformity between the rocks of Permian and Cretaceous age. To date, detailed mapping has been confined to a zone of thrust faults and related folds that surround a central lens of megabreccia. The thrusts dip toward the center, and the upper plates are displaced outward. Within each thrust plate the beds are buckled and locally cut by subordinate thrust faults and by steeply dipping normal, reverse, and tear faults. Horse blocks of the basement sandstone of Cretaceous age occur along the thrusts and tear faults. Eastward from the center of the structure, displacement on the

[57] U.S. Geological Survey, 1964, Astrogeologic studies annual progress report, August 25, 1962 to July 1, 1963: Part B.
[58] See footnote 57.
[59] See footnote 57.

thrust faults decreases, thrusts die out in asymmetrical anticlines with axial planes dipping back toward the center, and the intensity of buckling decreases. The additional data are compatible with the concept that the structure resulted from meteoritic impact.

Impact origin of Campo del Cielo craters confirmed

An expedition consisting of representatives from Lamont Geological Institute, Direction de Geologia y Mineria (Argentina), Mellon Institute, Carnegie Institute of Technology, and Daniel J. Milton [60] of the Geological Survey made the first detailed examination of the Campo del Cielo, an Argentine meteorite and crater field. The expedition confirmed the impact origin of craters, located and mapped seven craters, and acquired a newly found iron meteorite of about 3 tons for the U.S. National Museum. In addition, the number of small iron meteorites collected from this field was increased from a handful to more than 400, establishing Campo del Cielo as probably the largest known meteorite-strewn field. Excavation of the best preserved crater revealed charcoal that may represent wood buried beneath loose throwout and burned in a forest fire caused by the meteorite fall. Carbon ^{14} age of charcoal was determined by Wallace Broecker of Lamont Observatory as 5,800, ±200 years.

Impact characteristics of a rockfall, Little Colorado River, Ariz.

A group of fresh, low-velocity impact craters formed by a 950-foot rockfall of Toroweap Sandstone into the dry sand bed of the Little Colorado River, about 15 miles west of Cameron, Ariz., was studied by D. P. Elston and D. J. Milton.[61] One crater, having a diameter of 5 to 7 feet and a depth of 2 feet, was formed by impact of a block of sandstone weighing about 175 pounds into a nearly level, slightly coherent sand bank. An apron of ejecta was deposited asymmetrically in a direction dominantly away from the source of the rockfall and consisted of (1) a continuous blocky sand ejecta blanket extending from the crater lip to as much as 4 feet from the crater, and (2) a discontinuous sand ejecta blanket, in part raylike, that extended to about 14 feet from the crater. The blocky blanket formed a distinct "hummocky" crater rim deposit. Geologic relations indicate that the material of the discontinuous blanket was deposited upon and beyond the crater rim deposit and was derived from the deepest part of the crater. Fragments of the impacting projectile were deposited in elongate trains traceable up the crater wall, across the blocky ejecta apron, and into the raylike areas, forming the roughest material in the discontinuous blanket. Craters such as this provide a good approximation of secondary impact craters, which are thought to be important features contributing to lunar topography.

Origin of the Flynn Creek, Tenn., cryptoexplosion structure

Geologic mapping of the Flynn Creek, Tenn., cryptoexplosion structure has been completed by D. J. Roddy.[62] The field studies have delimited, in an otherwise undeformed area, a circular deformed rim of Ordovician rocks, about 2.2 miles in diameter, enclosing an intensely brecciated rock consisting of rock fragments of Middle and Late Ordovician age. The upper surface of the breccia is in the form of a crater, 300 feet deep, which contains a centrally raised structure of intensely disturbed rocks of Middle Ordovician age. The structure formed in the interval that includes Late Ordovician to early Late Devonian time. A thin marine deposit of bedded breccia and an anomalously thick section of Chattanooga Shale, including a crossbedded dolomite, possibly basal-most Chattanooga, of early Late Devonian age were deposited in the crater-form structure. The character of the breccia, the presence of shatter cones, the gross structural form, and the apparent lack of gravity and magnetic anomalies obtained from detailed geophysical surveys, are compatible with a meteoritic impact origin.

Experimental cratering phenomena

Work has continued by M. H. Carr [63] on the development of a rapid, inexpensive technique for explosively shock loading materials to permit the study of their behavior under varying pressure conditions. The most fruitful use of this technique is in shocking rock materials to known peak pressures so that the effects of known shocks on a variety of materials can be studied. This experimental technique can be used to obtain the Hugoniot curve, which relates specific volume of the rock material to pressure. It involves passing an explosively generated shock wave through an aluminum rod and then through the specimen. The time of passage of the shock wave past strain gauges on the aluminum and the specimen are measured, and the shock speeds are determined. From the two shock speeds, the shock equation of state can be determined by an impedance match solution, provided the shock wave in

[60] See footnote 57, p. A142.
[61] See footnote 57, p. A141.
[62] See footnote 57, p. A142.
[63] See footnote 57, p. A142.

the specimen is a single-step function. The technique, applied to copper, gave results that are in good agreement with the previously determined Hugoniot curve for copper. The results for Yule marble from Colorado indicate that a multiple wave structure is generated; thus an impedance match solution is invalid and no Hugoniot curve can be constructed. Results on basalt show that the measured speed of the shock wave is not pressure dependent and was virtually constant at 5.76 ±0.23 kilometers per second over the pressure range studied. These results are similar to that found for gabbro by other workers, and may result from measurement of an elastic precursor at pressures less than 200 kilobars.

EXTRATERRESTRIAL MATERIALS

GEOCHEMISTRY AND PETROGRAPHY OF TEKTITES

Systematic study of the mineralogy and chemistry of tektites from Australasia, southeast Asia, and the Philippine Islands strewn fields comprised a major part of the Geological Survey effort during 1963.

Characteristics of different groups of tektites

New analyses for major and minor elements and physical-property determinations on 6 australites and 6 javanites have been made by Frank Cuttitta, E. C. T. Chao, M. K. Carron, Janet Littler, J. D. Fletcher, and C. S. Annell.[64] New minor-element analyses have also been performed on 6 indochinites, 1 additional javanite, 15 philippinites, and 2 thailandites. The new data indicate that Australasian tektites comprise at least two distinct chemical populations which are characterized by differences in (1) indices of refraction and specific gravities, (2) MgO/CaO ratios, (3) Cr, Ni, and Co contents, and (4) Cr/Ni ratios. The analyzed australites are similar to philippintes in that both kinds of tektites have MgO/CaO less than 1 and have low Cr, Co, and Ni contents. Indochinites and javanites are characterized by MgO/CaO values greater than 1 and Cr, Co, and Ni contents that are higher, in general, than in australites and philippinites. Physical and chemical data, such as these, point toward a better understanding of the extent of intermixing of tektites within each of the various regions comprising the Australasian strewn field, and thereby, a means of reconstructing fall patterns.

[64] U.S. Geological Survey, 1964, Astrogeologic studies annual progress report, August 25, 1962 to July 1, 1963: Part C.

Mineralogy and chemistry of spherules in philippinites

E. C. T. Chao, E. J. Dwornik, and Janet Littler[65] have reported new mineralogic, petrographic, and chemical data on metallic spherules present in philippinites from the Ortigas site of Mandaluyoung near Manila, Philippines, and in indochinites from Dalat, South Viet Nam. Most of the spherules contain kamacite, schreibersite, and troilite. Schreibersite is interstital to the round or elongate, fine-grained kamacite, or forms blebs in a matrix of this kamacite. Where abundant, schreibersite forms a network throughout the entire spherule. Troilite generally comprises small round inclusions in the schreibersite. The amount of schreibersite in the spherules ranges from less than 5 to about 35 modal percent, and the troilite constitutes as much as 5 modal percent.

The composition of the phases present in the metallic spherules was determined by use of the electron probe. The kamacite from metallic spherules in 9 philippinites contains from 1.6 to 4.5 percent Ni. The average Ni contents of kamacite in each of 3 analyzed spherules from indochinites are 4.7, 10.0, and 12.9 percent. The average Ni contents in each of 4 schreibersite grains in a single indochinite spherule ranges from 12.1 to 15.8 percent.

The spherules in the tektites are very similar to the meteoritic spheroids from Meteor Crater, Ariz., in texture and mineral assemblage. It is concluded that the spherules in the tektites were formed as molten droplets from an impacting meteoritic body which was instrumental in producing the tektite glass.

Vapor pressure and fractionation in Philippine tektite melts

The vapor pressure and vapor fractionation of Philippine tektite melts of approximately 70 percent SiO_2 have been studied by L. S. Walter and M. K. Carron. The total vapor pressure at temperatures ranging from 1500°C to 2100°C is 190±40 mm Hg at 1500°C, 450±50 mm at 1800°C, and 850±70 mm at 2100°C. Determinations were made by visually observing the temperature at which bubbles began to form at a constant low ambient pressure. By varying the ambient pressure, a boiling-point curve was constructed. This curve differs from the equilibrium vapor pressure curve due to surface-tension effects. This difference was evaluated by determining the equilibrium bubble size in the melt and calculating the pressure due to surface tension, assuming the latter to be 380 dynes/cm.

[65] See footnote 64.

The relative volatility from tektite melts of the oxides of Na, K, Fe, Al, and Si has been determined as a function of temperature, total pressure, and oxygen fugacity. The volatility of SiO_2 is decreased and that of Na_2O and K_2O is increased in an oxygen-poor environment. Preliminary results indicate that volatilization at 2100°C under atmospheric pressure caused little or no change in the Na_2O or K_2O percentage. The ratio Fe^{+3}/Fe^{2} of the tektite is increased in ambient air at a pressure of 9×10^{-4} mm Hg ($=10^{-7.4}$ atm O_2, partial pressure) at 2000°C. This suggests that tektites were formed either at lower oxygen pressures or that they are a product of incomplete oxidization of parent material with a still lower ferric-ferrous ratio.

Development of spectrographic methods for small amounts of extraterrestrial material

The Geological Survey is conducting an extensive investigation of methods of quantitatively analyzing very small amounts of extraterrestrial materials because of the limited samples available. C. S. Annell [66] has investigated the analysis of solutions by emission spectroscopy as a technique for the quantitative determination of the major constituents of tektites and meteoritic materials. Use of rotating-disc apparatus in conjunction with high-voltage spark excitation produces the characteristic spectra of many elements present in these materials. The spectral intensities can be measured and quantitatively related to known standards. Studies of experimental factors show that excellent working curves covering the elemental ranges exhibited by known tektites are obtained for aluminum, iron, magnesium, calcium, and titanium. Methods for detecting or determining other elements present in tektites are being studied.

Spectrographic determination of low concentrations of Cs, Rb, and Li in tektites

A spectographic method for the determination of Cs, Rb, and Li in less than 10 parts per million concentrations in tektites has also been developed by Annell (p. B148–B151), A 1-ppm analytical limit for Cs was obtained using a 3-meter concave grating spectrograph. The method was primarily designed to determine the Cs content of tektites, with adaptation to Rb and Li determinations. The precision of the method was checked by duplicate determinations of Cs, Rb, and Li in bediasites from Texas and tektites from Southeast Asia and Indonesia.

[66] See footnote 64, p. A144.

Chemical determination of ferrous iron in small samples

M. K. Carron [67] has developed modifications of Wilson's [68] method for the determination of ferrous iron in milligram amounts of silicates. The modifications provide a means for high-precision determinations of ferrous iron in tektites using ordinary semimicro laboratory equipment. The method presented here employs more dilute solutions of vanadium, V, (0.00139*N*) than proposed by Wilson. The excess vanadium remaining in solution, after oxidation of the ferrous iron of the sample, is titrated with a 0.0139*N* ferrous ammonium sulfate solution, using a semimicro buret graduated to 0.02 ml. The results obtained by the proposed method show excellent agreement with those obtained spectrophotometrically.

X-ray fluorescence analyses of small samples of tektites

X-ray fluorescence analyses of tektites, using 50 milligram samples, have been performed by H. J. Rose, Jr., Frank Cuttitta, M. K. Carron, and Robens Brown (1–64). X-ray fluorescence spectroscopy had been applied previously in the analysis of materials of geologic interest, but larger samples had hitherto been required. Six Java tektites, representative of the range of indices of refraction and specific gravities from a large collection, were analyzed both by X-ray fluorescence and chemical methods, and the results were compared. The analyses, including those of the light elements, are closely similar. Determinations of SiO_2, Al_2O_3, total iron, K_2O, CaO, TiO_2, and MnO are in agreement with those obtained by conventional chemical techniques.

Partition of nickel among coexisting phases in basaltic achondrites

Metallic iron, occurring as a minor constituent in the basaltic achondrites, has been investigated by M. B. Duke. New electron-probe analyses and petrographic data have been obtained from kamacite in six eucrites and one howardite. The low nickel content of kamacite in eucrites has been verified. Emission spectrographic analyses for nickel in pyroxene from several types of stony meteorites [69] and new electron-probe analyses for nickel in the coexisting kamacite give a distribution factor that is in fair agreement with experimental determinations at atmospheric pressure and magmatic temperatures. The low nickel content of the metal and

[67] See footnote 64, p. A144.

[68] A. D. Wilson, 1960, The micro-determination of ferrous iron in silicate minerals by a volumetric and colorimetric method: The Analyst, v. 84, p. 823–827.

[69] M. B. Duke, 1963, Petrology of the basaltic achondrites: California Institute of Technology, Ph. D. dissert.

the generally low total nickel content of the basaltic achondrites are interpreted as due to fractionation between metal and silicate phases during magmatic differentiation of the basaltic achondrites. The nickel distribution supports other mineralogical and textural evidence that these rocks formed at relatively low pressures.

Iron content of metallic copper in achondrite

Metallic copper from the Norton County, Kans., achondrite has been investigated by M. B. Duke in collaboration with Robin Brett, of the Carnegie Geophysical Laboratory. Electron-microprobe analyses of the copper indicate an iron content of 4.2 weight percent (Keil and Fredriksson [70]). However, phase equilibria relations from the system Cu-Fe-S (R. A. Yund, oral communication) suggest that the copper was formed below 475 $\pm 25°$C, the temperature at which iron solubility in copper is negligible. Therefore, new electron-probe microanalyses were made of copper grains (5μ to 20μ) from the chondrites. Iron contents ranging from 1.1 to 4.5 weight percent were obtained. Determinations varied within single copper grains, suggesting that analytical uncertainties were involved.

In order to assess the magnitude of CuK-induced FeK radiation arising from outside the analyzed copper grains, four iron fragments were polished and given coats of metallic copper ranging from 0.8 to 3.5μ in thickness. These were analyzed using microprobes of the Applied Research Laboratory and U.S. Geological Survey. The intensity of induced FeK radiation apparently decreases exponentially with the thickness of the copper layer, but is equivalent to 3 weight percent or more for iron covered by 3.5μ of copper. The lower the excitation potential or the lower the X-ray take-off angle, the smaller is the fluorescence effect. On the basis of the phase equilibria data and the experiments with copper-coated iron, it is suspected that the analyzed values of iron in copper are unreasonably high due to fluorescence effects. It is necesary, therefore, to analyze large grains or to separate the copper from the matrix in order to determine the true iron content.

Electron microprobe analyses of metallic spherules in impactite

Using the electron microprobe, E. J. Dwornik and R. R. Larson found that nickel content in 12 metallic spherules in impactite from Wabar, Saudi Arabia, ranges from 12.2 to 45.2 percent. Cobalt was noted in minor amounts in those spherules with high nickel content. In a continuing study of "cosmic particles," the same workers analyzed qualitatively five particles from a suite collected recently by C. W. Crozier from the summits of Mt. Wittington, N. Mex. The particles ranged in size up to 80 microns. Iron was the major constituent in all particles. In one instance titanium was also found, and in another, silicon and calcium. In three particles from the San Augustine Playa deposit, only iron could be detected. Nickel was found in seven metallic spherules from tektites from the Ortigas site, Philippines, to range from 2.2 to 4.5 percent, and from three spherules from Dalat indochinites to range from 4.7 to 12.9 percent. The analysis of nine additional metallic spherules submitted by W. D. Crozier showed only iron. Four of the particles were collected from the atmosphere atop Mt. Wittington, N. Mex., the others from a depth of 3 feet from the San Augustine playa nearby. No differences are apparent in these two suites of spherules, suggesting that the particles are not industrial contaminants. Four additional black metallic "cosmic" spherules also analyzed again showed major Fe only.

[70] Keil, Klauss, and Fredriksson, Kurt, 1963, The light-dark structure in the Pantar and Kapoeta stone meteorites: Geochim et Cosmochim. Acta, v. 27, p. 717–739.

MAGNETIC SUSCEPTIBILITY AND ELECTRICAL RESISTIVITY OF TEKTITES

Magnetic susceptibility of tektites

Magnetic-susceptibility measurements by A. N. Thorpe and F. E. Senftle on 18 tektites from various strewn fields have shown a relatively large temperature-independent component of the magnetic susceptibility in all tektites studied. The data indicate that this component is the result of submicroscopic iron spherules in the tektites. An investigation of the color of tektites in terms of the magnetic measurements and of the optical absorption spectra suggests that the basic color of all tektites is green or greenish blue. The brown to black coloration in some tektites appears to be due to finely dispersed Fe_2O_3 and (or) many submicroscopic metallic spherules.

The magnetic properties of metallic spherules in tektites from Isabela, Philippine Islands, have been investigated by F. E. Senftle, A. N. Thorpe, and R. R. Lewis (1–64). Five metallic spherules from a single tektite (P_I–73) were studied. They ranged from 0.02 to 0.04 cm in diameter and from 0.07 to 0.28 mg in mass. An electron-probe analysis of one spherule confirmed the report of Chao and others [71] that silicon, if present, is less than a few tenths of a percent.

Magnetic-susceptibility measurements on the spherules were made by the Faraday method using a quartz helical spring balance. Measurements were taken at temperatures ranging from 303°K to 77°K. The susceptibility was found to be independent of temperature and approximately the same in all spherules for given field strengths up to 6,000 oersteds. Measurements of magnetic susceptibility as a function of field strength at 298°K and 77°K showed that saturation occurs at relatively high field strengths compared to the saturation of pure iron. The specific magnetization of two of the spherules is about 1.85 Bohr magnetons per atom in fields in excess of 6,000 oe. The permeability of the spherules is close to 1.38.

The large field- and temperature-independent susceptibility (0.03 emu/g) is not to be expected for an iron alloy of the composition of the spherules (about 3 percent Ni and 97 percent Fe). Some Ni and low-Si iron alloys lack magnetic saturation except at high fields, as do the spherules; however, such alloys have very large permeabilities in contrast to the low permeability of the spherules. Also, the specific magnetization of the spherules is much higher than would be expected for a low-Ni iron alloy, but can be accounted for by the presence of Fe-Ni phosphides. These considerations indicate that the apparently abnormal magnetic properties of the spherules cannot be a direct result of their chemical composition.

The field-independent susceptibility of the spherules, except in very high fields, indicates the absence of a magnetizing field within the spherule. Considerations of the resultant field inside a spherule as a function of the applied field, the shape of the spherule, and the saturation magnetization shows that the field- and temperature-independent susceptibility is a direct result of the shape of the spherules.

The saturation of the spherules at relatively high field strengths indicates that the use of the equation of Owen [72] and Honda [73] to detect gross ferromagnetic impurities in tektites is valid only if there are no spherules present. Thus, the presence of spherules less than 1μ in diameter cannot be detected by this method or by microscopic examination.

Senftle, Thorpe, and Lewis (1–64) have also found that measurement of magnetic susceptibility as a function of temperature is a possible technique for the detection of submicroscopic metallic spherules. The presence of a temperature-independent component of the susceptibility appears to indicate the presence of spherules. If the presence of spherules is established for tektites in general, it will give additional evidence of a meteoritic origin for tektites when combined with the known existence of relatively high phosphorus and nickel contents of the metallic spherules.

Relation of electrical resistivity to viscosity of tektites

The electrical resistivity of tektites is being investigated with the hope of correlating it with the viscosity. A relation has been found between the electrical resistivity and viscosity of glasses of simulated tektite composition. The average value of the activation energy for electrical resistivity has been found to be 21.3 kilocal/gram and the average activation energy for viscosity has been found to be 3.9 times this value.

SPACE-FLIGHT STUDIES

Method for measuring lunar slopes

An increasingly important part of the Geological Survey investigations for NASA is aimed at determining those characteristics of the lunar surface that are important in designing the manned and unmanned space vehicles and attendant scientific missions. During the past year, a photometric technique for measuring the lunar slopes throughout the equatorial belt and at potential landing sites within the belt was developed by D. E. Wilhelms.[74] This technique is based on the functional relation between brightness of the lunar surface, of the angle of incidence of the Sun's rays, and the local slope of the surface. Areas of interest are traversed by a microphotometer to measure the amount of light transmitted by a lunar photograph. The record is in the form of both an inked line on a chart and a punched paper tape. With the chart, the curve which passes through horizontal segments of the lunar surface can be drawn for each albedo unit (normal albedo must be mapped in advance by other techniques using full-moon photography). The curve then serves as a comparison curve against which brightness of sloping surfaces can be matched. Angular distances in lunar longitude from the terminator, which closely correspond to the angle of elevation of the sun's rays from the local horizontal surface, are scaled

[71] E. C. T. Chao, J. J. Fahey, Janet Littler, and D. J. Milton, 1962, Stishovite, SiO_2, a very high pressure new mineral from Meteor Crater, Arizona: Jour. Geophys. Research, v. 67, p. 419–421.

[72] M. Owen, 1912, Magnetochemisch Untersuchungen die thermomagnetischen Eigenschaften der Elemente, 2: Ann. Physik, v. 37, p. 657–699.

[73] K. Honda, 1910, Die thermomagnetischen Eigenschaften der Elemente: Ann. Physik, v. 32, p. 1027–1063.

[74] U.S. Geologic Survey, 1964, Astrogeologic studies annual progress report, August 25, 1962 to July 1, 1963: Part D.

off on the chart. By measuring the difference in longitude between the segment of unknown slope and the point of equal brightness on the comparison curve, the calculation of the slope is readily made. The average slope of an area can be measured, and terrain maps showing areas of similar slope distribution can be constructed.

By recording the microphotometer measurements on punched tape, the data can be transferred readily to a computer where the calculations can be performed automatically. J. F. McCauley has successfully automated the technique, including derivation of the comparison curves, and applied it to a large portion of the lunar equatorial belt, using existing telescopic photographs. In the future, when photographs obtained from spacecraft become available, it should be possible to measure slopes of smaller segments than 0.75 kilometers by refinement of the technique. Terrain maps obtained by this method are of importance in planning unmanned and manned spacecraft landings.

Isotonal map of the Lansberg region

R. J. Hackman has constructed an isotonal map of the Lansberg region by densitometer traverses of a high-contrast, positive transparency of a full-moon photograph. The lines of traveres were automatically plotted on a Cronopac print, simultaneously with the densitometer traverses of the transparency, and the densitometer curves also were recorded simultaneously on graph paper. The curves were divided into density units by periodic comparison with the curve for a standard density wedge. Traverse segments corresponding to each of the density units were plotted on a 1 : 2,000,000 enlargement of the photograph. With these segments (along with 600 spot measurements) as control, and tonal patterns as visual aids, isotonal lines connecting points of equal density were drawn on the photograph. For the final portrayal of the map, the isotonal lines were transferred to ACIC Mercator projection lunar topographic charts by means of a Sketchmaster.

Similar tone values are often a clue to correlation of lunar geologic units separated from one another. An isotonal map such as the one compiled correlates tones with greater precision than the unaided eye because the eye is influenced by surrounding tones. Also, small tonal variations that would escape the eye are detected by the densitometer. Isotonal maps are a prerequisite to the construction by photometric methods of lunar terrain maps, as described above, because effects of albedo must be separated from effects of variation in slope.

Infrared emission studies of lunar material

In other investigations, the properties of the lunar material are being determined from infrared emission studies being conducted by Kenneth Watson.[75] Both broad-band and narrow-band emission within the two major atmospheric windows of 8–14μ and 18–24μ will be examined. The broad-band studies will provide information on the distribution of thermal properties at and near the surface, while narrow-band studies will primarily provide information on the grain-size distribution of the lunar material and possibly, in the case of bright-ray craters, a limited amount of compositional analysis. An important line of research will be the computation of models, supported by experiment and observation, to explain the infrared emission. At present, studies are being made on the use of models of the lunar photometric function to derive the variation of absorbed solar energy as a function of the inclination of the Sun's rays. These data, coupled with model and laboratory studies, will aid in differentiating geologic units.

Density of small craters on the lunar surface

H. J. Moore has made calculations of the density of small (telescopically unobservable) craters on the lunar surface. The results differ significantly from extrapolations of frequencies of telescopically observable craters 1 kilometer in diameter or larger. By combining data on hypervelocity impact cratering and data on the distribution of interplanetary dust, micrometeoroids, meteoroids, and asteroids, it is calculated that a billion-year-old surface composed of rock and sand would be completely covered with primary craters of all sizes up to 1 meter across in various stages of destruction. If craters 100 meters in diameter are destroyed by erosion and infilling in a billion years, about 10 percent of such a surface could be covered by well-preserved craters between 1 and 10 meters in diameter, 10 percent by well-preserved craters between 0.1 and 1 meter, and 10 percent by well-preserved craters between 0.01 and 0.1 meter. The remaining surface area would be covered by primary craters 0.01 to 10 meters in diameter that are more than three-tenths destroyed, by rare larger craters, and by secondary impact craters. Higher rates of crater destruction, as might result from flow of material or burial by volcanic products, would substantially alter these predictions. A smaller crater density is expected on surfaces younger than 1 billion years.

[75] See footnote 74, p. A147.

Effect of increasing crater size on effective target strength in basalt

H. J. Moore, D. E. Gault, and E. D. Heitowit have shown experimentally that there is a decrease in effective target strength in basalt with increasing size of hypervelocity impact craters. The results are consistent with defect theory, which predicts a decrease in strength with increasing size of specimens containing defects. The experiments refute predictions that the amount of mass ejected for each unit of projectile energy (corrected for the projectile-target density ratio) should be constant.

Search for dust clouds near libration regions of the Moon

The possible existence of dust clouds near the L_4 and L_5 libration regions of the moon was investigated by E. C. Morris, J. Ring, and H. G. Stephens [76] from Mt. Chacaltaya, Boliva. The libration points, lying in the orbital path of the Moon 60° ahead of and behind it, are points of equilibrium where centrifugal forces balance gravitational forces. It was hoped to observe clouds of particles ("Kordylewski's clouds") which may be trapped at these points. From June through November 1963, 17 photographic plates of L_4 and 28 plates of L_5 were taken with a 12-inch focal length aerial camera. Visual examination and microphotometer measurements of the plates failed to show any brightening in the region of the libration points. Further statistical analysis of the plates is planned. In addition, photoelectric scans were made with a 6-inch-diameter Maksutov-Cassegrain telescope. Data from the scans are being reduced; preliminary reduction shows no indication of the presence of a cloud. With further reductions, it is hoped to place an upper limit on the possible cloud brightness, and particle density corresponding to this brightness will be calculated.

Statistical analysis of microphotometer data

Research in statistical analysis of microphotometer data from full-moon photographs has been continued by A. T. Miesch and C. W. Davis.[77] Their results have shown that variations in albedo, textural properties of the albedo patterns, and the regional gradation of the albedo can provide statistics useful in quantifying the observations made during lunar geologic mapping. Thus, correlation between rock units is made easier, and a better understanding is achieved of the nature of the variations in reflectivity.

[76] See footnote 74, p. A147.
[77] See footnote 74, p. A147.

GEOPHYSICAL INVESTIGATIONS

STUDIES OF THE CRUST AND UPPER MANTLE

Rocky Mountains divide United States into two crustal and upper-mantle superprovinces

The crust of the earth is separated from the deeper mantle by the Mohorovicic (M) discontinuity or "Moho." Specific new results on the thickness of the crust and seismic-wave velocity in the upper mantle have been obtained by the Geological Survey in the Middle Rocky Mountains of Idaho, Utah, and Wyoming (C.R. Willden, unpublished data), the Colorado Plateaus of Arizona and Utah (Roller, 1–63), the Coastal Plain of Mississippi (Healy and others, 1–64) and the Central Lowlands of Missouri (Stewart and Stauder, 1–64). Additional information has also been obtained in areas previously studied, particularly the Basin and Range province of Nevada and Utah (Eaton and others, 2–64; Roller, 1–64). These new results, combined with previous results, permit the generalization that the conterminous United States is divided by the Rocky Mountain System into two crustal and upper-mantle superprovinces. The investigations upon which this conclusion is based were largely supported by the Advanced Research Agency, Department of Defense, as a contribution to the VELA UNIFORM Program.

The western superprovince includes the Pacific Mountain System, the Intermountain Plateaus, and the Rocky Mountain System. It has the following properties: (1) The velocity of compressional waves in the upper-mantle rocks is everywhere less than 8 kilometers per second, except along the margin of the Pacific Ocean Basin, (2) the mean-crustal velocity is generally less than 6.4 km/sec, (3) the crust is generally thinner than 40 km, and (4) the crust seems to be divided into two fairly distinct layers by a boundary or velocity-transition zone that separates the upper crust with a compressional-wave velocity of about 6 km/sec from the lower crust (intermediate layer) with a compressional-wave velocity of about 7 km/sec. There are important regional variations in the thickness of crustal layers within the western superprovince, but the upper mantle seems to be fairly uniform. For example, the upper surface of the intermediate layer is less than 10 km deep in the Snake River Plain, and the thickness of the crust there is 40 or 45 km (Hill and Pakiser, 1–63), whereas the upper surface of the intermediate layer is about 15 or 20 km deep in the Middle Rocky Mountains, and the thickness of the crust there is about 35 km (C. R. Willden, unpublished data).

The eastern superprovince includes the Interior Plains, the Interior Highlands, the Appalachian Highlands, and the Coastal Plain. It has the following properties: (1) the velocity of compressional waves in the upper-mantle rocks is everywhere greater than 8 km/sec, (2) the mean-crustal velocity is generally greater than 6.4 km/sec, (3) the crust is generally thicker than 40 km, and (4) evidence for separation of the crust into distinct layers is less convincing than in the west. The velocity of compressional waves in the crust may increase continuously with depth from about 6 km/sec just beneath the veneer of sedimentary rocks to as much as 7.5 km/sec just above the M-discontinuity. As in the western superprovince, there are important regional variations in the thickness of the crust; the degree of uniformity of the upper mantle is still a matter for debate and further experimentation. One example of such regional variation is the observation that material of compressional-wave velocity 6.6–6.8 km/sec is present at depths of only 5–10 km in the Lake Superior region (Steinhart, 1–64), whereas material of this velocity is present only at depths of 20 km or more in the Great Plains Province (Jackson and others, 1–63).

Laboratory measurements of density and seismic velocity, gravity measurements, and considerations of isostasy indicate that crustal and upper-mantle densities vary directly with velocity, so the western superprovince is characterized by low crustal and upper-mantle densities, and the eastern superprovince by relatively high densities.

The Late Mesozoic and Cenozoic diastrophism, plutonism, and volcanism have been widespread in the western superprovince, whereas the eastern superprovince has been relatively stable and quiescent during the past 100 million years or so. The crust and upper mantle in the western superprovince can be thought of as youthful—still in the process of evolution. The crust and upper mantle in the eastern superprovince can be thought of as mature. This concept is supported by aeromagnetic measurements analyzed by Isidore Zietz. These measurements reveal anomalies of large amplitude in the eastern superprovince and a relatively featureless magnetic field in the western superprovince, suggesting, along with the geology and observations of mean-crustal velocity and density, that the crust in the west is now receiving mafic material from the mantle, whereas the mature crust in the east has already been extensively intruded with material from the mantle.

Cooperative experiments in seismology

Eight Geological Survey seismic stations were among the 46 stations representing 14 U.S. and Canadian institutions that recorded seismic waves generated by 82 one-ton explosions in Lake Superior in July 1963 (Steinhart, 1–64). Geological Survey recording units provided about one-fifth of the more than 3,000 seismograms recorded in this first United States–Canadian cooperative experiment of the international upper mantle project. The Geological Survey has also cooperated extensively with St. Louis University in improving seismic traveltimes for location of earthquakes in southeast Missouri (Stauder and others, 1–64), and in studying crustal structure in Missouri (Stewart and Stauder, 1–64).

The Geological Survey has cooperated with the Advanced Research Projects Agency, Air Force Technical Applications Center, California Institute of Technology, and University of California (San Diego) to make a detailed study of crustal structure in the vicinity of the Tonto Forest Seismological Observatory near Payson, Ariz., with the objective of improving the seismic identification capability of the observatory.

Data processing of seismic records

The Geological Survey is making extensive use of automatic and semiautomatic methods of analyzing seismic data. For example, a six-channel analog-to-digital converter that converts analog magnetic tape recordings to digital records is being used in the Survey's Denver data-analysis laboratory for computer processing (Healy and Warrick, 2–64). Preliminary research with digital processing has been directed toward selecting processors that help the seismologist to identify events on seismograms and to measure their amplitudes and apparent velocities. A final evaluation of the usefulness of digital processing in the interpretation of refraction seismograms is not possible at this time, but the following conclusions are suggested by the preliminary work: (1) It is difficult to codify and program the function of the seismologist in seismic interpretation, and it may never be practical to remove him completely from the process of interpretation, (2) automatic processing enables the seismologist to make precisely defined and accurate measurements on many more seismograms than can be handled practically by a seismologist without automatic processing, (3) automatic processing detects events on seismograms that are missed in routine interpretation by the seismologist. These advantages will probably justify the effort and expense of digital processing.

A new analog system for processing magnetic-tape recordings has also been installed in the Survey's Denver data-analysis laboratory, and it is now in use.

Portable seismic recorders

An intensive effort is being made by the Geological Survey to develop highly portable seismic-recording equipment for studies of small earthquakes and aftershocks. A new portable seismic-recording system developed recently permits unmanned operation for up to 10 days (Hoover, 1–64). The heart of the seismic-recording system is a tape recorder developed to meet strict performance specifications for low weight, low power, small size, long recording time, and high dynamic range. The record-only transport uses ½-inch-wide magnetic tape and provides up to 7 data channels and 2 edge channels. The 35-pound recorder, with a bandwidth from direct current to 17 cycles per second, operates over wide environmental conditions without need for special precautions. A prototype seismic system has been developed around the new type recorder. The Geological Survey will use 20 of these systems for studies of aftershocks and small earthquakes, and also to augment its long-offset refraction studies of the earth's crust, particularly in remote areas.

Geothermal investigations

The first heat-flow determination on an island arc, excluding Japan, was made by W. H. Diment and J. D. Weaver (2–64) near Mayaguez, Puerto Rico. In addition to finding a low value of heat flow, 0.6 microcalorie per square centimeter per second, they showed that the history of land use may be important in determining the thermal regime. Curvature of the plot of temperature versus depth for the location is tentatively attributed to a 1-degree increase in temperature caused by clearing of forests for cane fields several hundred years ago.

In order to provide a basis for understanding the variations in thermal conductivity of ultramafic rocks and for estimating conductivity from a knowledge of mineral composition, W. H. Diment has compiled new and published data on the thermal conductivity of serpentinites and minerals commonly comprising them, such as antigorite, chrysotile, olivine, pyroxene, amphibole, talc, magnesite, magnetite, and brucite.

Determinations of terrestrial heat flow were obtained near Oak Ridge, Tenn. (Diment and Robertson, 1–63), and Washington, D.C. (Diment and Werre, 3–64). These measurements plus three in progress and those in the literature indicate a deviation of less than 30 percent from a mean of about 1 microcalorie per cm^2 sec in eastern North America. Although the measurements are sparsely distributed, their uniformity suggests that heat flow is rather uniform throughout some regions and that the extreme range of continental heat-flow values is the result of processes occurring within the mantle or deep crust. It may thus be practicable in some large regions to estimate temperatures at depth on the basis of reasonable estimates of the thermal conductivities of its rocks and only a few heat-flow determinations.

From drifting station Ice Island T–3, B. V. Marshall, J. P. Kennelly, Jr., E. P. Smith, and A. H. Lachenbruch have recovered cores and measured temperatures in the bottom sediments in the Arctic Ocean. This continuing study so far includes measurements at 20 locations within a region roughly 100 kilometers on a side, between lat 82° and 83° N. and between long 156° and 164° W.; half the region lies in an abyssal plain, the Canadian Basin, and half lies on the flank of a suboceanic rise, the Alpha Rise. A preliminary interpretation by Lachenbruch and Marshall (1–64) shows a systematic change of the heat flux from 1.40 microcalories per cm^2 sec, ±5 percent, in the abyssal plain (water depth, 3,740 meters) to about 0.8 microcalories per cm^2 sec at the shallowest station on the rise (water depth, 2,215 m).

In a study of the geologic and hydrologic factors that control local variations in heat flow, A. H. Lachenbruch, G. W. Greene, and R. J. Monroe have made temperature measurements to depths of several thousand feet in 19 holes within a 1,000-square-mile region of complex geology in southern Nevada. Preliminary results show that the thermal gradients within a single formation range from one hole to another by a factor of three.

THEORETICAL AND EXPERIMENTAL GEOPHYSICS

Paleomagnetism

Investigators engaged in paleomagnetic studies have now acquired enough data to establish the theory of reversals of polarity of the earth's main magnetic field and to date the intervals during the last 4 million years when the field has been "normal," as it is now, or "reversed," approximately opposite its present direction.

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Using their extensive measurements of remanent magnetization and absolute age (by the K–Ar method) of rocks from the Hawaiian Islands, Alaska, and Western United States and data published by other workers, R. R. Doell, Allan Cox, and G. B. Dalrymple recognize four major intervals, termed "polarity epochs," during which the magnetic field has had a single polarity: (1) reversed, from greater than 4.0 to 3.5 million years ago, (2) normal between 3.5 and 2.5 m.y. ago, (3) reversed between 2.5 and 1.0 m.y. ago, and (4) normal from 1.0 m.y. ago to the present. Intervals of relatively short duration (about 100,000 years) have also occurred during which the polarity of the field was opposite that of the respective epoch. These intervals have been termed "polarity events," and two are presently recognized: (1) a reversed event about 3.1 m.y. ago, and (2) a normal event about 1.9 m.y. ago.

Artificial iron-formation, made by stacking magnetite-bearing and magnetite-free bakelite disks, has been found by C. E. Jahren (1–63) to have the same range of susceptibility anisotropy as natural layered samples. The anisotropy increases with increasing layer susceptibility and is largely independent of the details of layering when less than half the volume of the sample is magnetic material.

Triassic diabases and contact-metamorphosed sediments from southeastern Pennsylvania show a considerable range of intensity of magnetization and of magnetic susceptibility, according to preliminary results of a study by M. E. Beck, Jr. Within diabase units the mafic facies are in general more strongly magnetic than late-stage felsic differentiates, and the ratios of remanent to induced magnetization appear to be greater for the finer grained rocks. Within the contact aureole, remanent magnetization and magnetic susceptibility range more widely, in complex relation with the composition of the original sediment, the degree of baking, and the amount of titanomagnetite introduced by hydrothermal solutions. After removal of unstable components, specimens have a "normal" direction of remanent magnetization, very nearly corresponding to the axial dipole position inferred from previous measurements on Triassic rocks of the Eastern United States. Significant deviations from the mean direction exist from one locality to another that probably indicate secular variation of the geomagnetic field; some may have resulted from undetected differences in the amount of structural deformation.

Elastic properties of calcite redetermined

Using improved ultrasonic pulse-echo instrumentation yielding velocities reproducible to ±0.2 percent, Louis Peselnick and R. A. Robie (1–63) have rederived the elastic constants of calcite as follows (in 10^{11} dynes per square centimeter): c_{11}, 14.45±0.10; c_{33}, 8.31±0.05; c_{44}, 3.263±0.03; c_{12}, 5.71±0.10; c_{13}, 5.34±0.20; c_{14}, −2.05±0.06. The values of some of the constants were found to be disproportionately sensitive to errors in crystal orientation; for example, a 1-degree error in the polar angle in the YZ plane results in an error of about 1 percent in velocity but an error of about 15 percent in the elastic constant, c_{13}.

Rock deformation

As a result of a review of time-dependent strain in rocks as a function of temperature, stress difference, and hydrostatic pressure, E. C. Robertson has determined that the theory of viscoelasticity is inapplicable to problems involving rocks in the crust, with the possible exception of unconsolidated water-bearing sediments. The rate of postglacial rebound in Fennoscandia and brittle fracture of salt under loading from nuclear blasts can be predicted at least qualitatively from a preliminary relation evolved. A hyperbolic sine function of stress difference fits the strain-rate data over 10 orders of magnitude for aluminum, copper, steel, and Yule marble; the temperature effect is satisfied by the negative exponential relation of the Arrhenius rate equation up to 80 percent of the melting point. Fracture follows creep as the principal mechanism of failure in metals and rocks at a critical stress near the inflection point of the curve of stress difference versus strain rate.

Migration of radon isotopes

A. B. Tanner has made an extensive review of the migration of radon isotopes in the ground. In all but very exceptional circumstances, radon-222 concentration undergoes hundredfold diminution by radioactive decay during migration through distances of several meters or less. The underground migration distances of the shorter-lived isotopes, radon-220 (thoron) and radon-219 (actinon), should be measured in centimeters and millimeters, respectively.

Electrical properties of iron-formation

F. C. Frischknecht and G. I. Evenden have tested the turam electromagnetic method over lenses of metamorphosed iron-formation in the Oakfield Hills area, Smyrna Mills quadrangle, Maine. Using an insulated loop for excitation, they obtained large anomalies from which the magnetic susceptibilities and thicknesses of the lenses could be estimated. When a long grounded wire was used for excitation, the anomalies were complicated by effects of galvanic currents.

Aerial infrared investigations

Aerial infrared imagery was acquired of the Salton Sea, Calif., geothermal area and the Steamboat Springs hot springs area, Nevada, in cooperation with the University of Michigan Infrared Radiation Laboratories. Preliminary study of the Salton Sea area imagery by S. J. Gawarecki indicates that previously known mud pots are detectable, except for one now submerged by the sea. Infrared images of the Steamboat Springs area show a series of hot springs whose alinement suggests that they are associated with a previously mapped fault zone.

Comparison of infrared imagery with conventional photography of part of the Shenandoah Valley, Va., by S. J. Gawarecki, discloses that many old drainage channels, sinkholes, and emerging subterranean streams, not readily visible on conventional aerial photography, are clearly visible on the infrared imagery. The recognition of these features suggests that infrared imagery may have particular application to ground-water and engineering-geology studies. Thick soils obscure much of the bedrock. Differences in vegetation, however, in part correspond to differences in lithology. Some differences in vegetation are visible on the imagery and assist in mapping contacts.

Automatic contouring of aeromagnetic anomalies

G. E. Andreason's studies of magnetic models for interpretation of aeromagnetic anomalies have been facilitated by adoption of a U.S. Weather Bureau program for automatic contouring and curve drawing. An accurate and reproducible map can now be prepared from model data in less than 1 minute instead of the 1 to 3 days required for hand contouring. The automatic contouring system is expected to be applicable to production of magnetic and gravity maps from field data as well as from model studies.

Calculation of depth of magnetic anomalies

R. G. Henderson has found that the mathematical process of downward continuation, by which the magnetic field is computed for points in planes successively closer to the source of an anomaly, may be used effectively to estimate maximum depth to juxtaposed magnetically different rock bodies. He is also reporting improvement in surface trend analysis (fitting of polynomial surfaces by recourse to orthogonal polynomials) and is making a comparative study of this essentially statistical method with analytical methods based on potential theory.

Geophysical Abstracts

The Geological Survey continued publication of Geophysical Abstracts for the thirty-sixth year of the publication. Abstracts were derived from more than 500 journals in 20 languages. The staff and volunteer abstracters cover literature pertaining to physics of the solid earth, application of physical methods and techniques to geologic problems, and geophysical exploration.

SOLID-STATE STUDIES

Luminescence and thermoluminescence studies

Basic studies of luminescence are continuing on cesium iodide. The fact that the temperatures of the thermoluminescence "glow" peaks are characteristic of the host crystal and not of the type of impurity has been firmly established. The emission spectra of the glow peaks is a function of the type of impurity. A model has been developed showing that the thermoluminescence "glow" peaks can be due to the migration of holes at characteristic temperatures. The experimental data confirm such a model for cesium iodide at low temperatures, and a preliminary report of this work has been published by Martinez, Senftle, and Page (1–64).

Besides the two modes of decay previously reported [78] for "pure" cesium iodide, a third mode having a decay time of 13–15 microseconds has been found. The emission of this mode is in the ultraviolet but at a somewhat longer wavelength than the other two modes. A more precise measurement of the emission of all three modes is planned with a new fast-scan monochrometer now being built.

Luminescence studies of zircon have been started, and an attempt is being made to correlate thermoluminescence with natural radiation damage. The thermoluminescence spectrum changes with, but is not consistent with, the amount of damage.

[78] F. E. Senftle, P. Martinez, and V. Alekna, 1962, Temperature dependence of decay times and intensity of alpha particles in pure and thallium activated cesium iodide: Rev. Sci. Instruments, v. 33, no. 8, p. 819–822.

Magnetic susceptibility measurements

In connection with the magnetic studies of coffinite, it was found necessary to investigate the magnetic properties of some associated compounds to aid interpretation. Magnetic susceptibility measurements have been made on $UO_2 \cdot xH_2O$ for $x=1.78$ to $x=2.13$, and from 77°K to 375°K. As the value of x decreased, the susceptibility increased. Both these data and structural arguments imply that the formula of this compound is $U(OH)_4$ rather than the dihydrate form. Based on this concept, the data have been corrected for diamagnetism and also for small amounts of UO_2 and H_2O which were present. The molar susceptibility of U^{+4} in $U(OH)_4$ is nearly an order of magnitude less than in other uranium compounds, and it is suggested that this is probably due to superexchange between adjacent uranium atoms through intervening oxygen atoms. The results of this study have been reported by Pankey, Senftle, and Cuttitta (1–63).

A detailed study of the magnetic properties of zircon has been initiated by F. E. Senftle and R. R. Lewis. By measuring the change in magnetization as a function of the accumulated time of heating at 853°K in a hydrogen atmosphere, it has been shown that the iron in zircon is primarily in the Fe_2O_3 form. The observed change in magnetization is due almost entirely to the reduction of surface Fe_2O_3.

Magnetic susceptibility measurements have been made by A. N. Thorpe on Pd, Pd–H, and Pd–D systems from 4.2°K to 300°K. With H/Pd or D/Pd of over 0.6 the system is diamagnetic at about the same value, that is, -0.074×15^{-6} electromagnetic units per gram. In all cases the susceptibility reaches a maximum at 70°K, but if the hydrogen or deuterium is desorbed to ratios of about 0.5, the susceptibility does not pass through a maximum value. This has a significant effect on the theory of the magnetic susceptibility and is being studied in more detail.

Magneto-acoustic studies

The magneto-acoustic pulse-echo technique was used by A. F. Hoyte and E. V. Mielczarek to study the shape of the Fermi surface of potassium. Single crystals of potassium were grown by a modified Bridgman method using a two-section stainless steel crucible. The faces of the crystals were cut and polished flat to within 0.001 inch, and their orientations were determined by X-ray crystallographic methods.

The measurements were made at a frequency of 94.7 millicycles per second and at a temperature close to 4.2°K. The high-frequency sound wave was propagated in the (111) direction—the growth direction of the single crystals. The crystals were rotated a total of 70° in the magnetic field, which was kept perpendicular to the propagation direction. This was later determined by X-ray crystallography to be a rotation from the (110) direction through the (011) to the (134) direction. Thus the complete symmetry of the Fermi surface perpendicular to the (111) direction was studied.

One and a half oscillation periods (2 minima and 1 maximum) were observed, and from these the Fermi surface was determined to be spherical within an experimental error of 12 percent. The average value of the Fermi momentum measured was 0.97×10^{-19} gram-centimeters per second, and this is in good agreement with the theory by F. S. Ham which predicts an anisotropy of about 1 percent in the Fermi surface of potassium with an average Fermi momentum of 0.87×10^{-19} gram-centimeters per second.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

FIELD STUDIES IN PETROLOGY AND GEOCHEMISTRY

Studies of silicic plutonic rocks

In the course of a comprehensive study of approximately 250 analyses of "Laramide" igneous rocks of central and western Colorado, George Phair has found that intrusive stocks throughout the State show a strong correlation between petrochemical type and regional gravity. Calc-alkaline stocks tend to be associated with regional gravity lows, whereas alkalic stocks tend to be associated with regional highs; alkali-calcic stocks predominate in a broad area of intermediate gravity between the highs and lows. Implications of these correlations on crustal structure and the origin of magma types are under investigation.

As part of an intensive study of the Sierra Nevada batholith in California and Nevada, F. C. Dodge has found that the composition of amphiboles from the various plutons of the batholith shows little variation and is independent of rock composition. The implication is that conditions within the various plutons were similar during formation of the amphiboles.

R. I. Tilling (chapter D), in a similar study of the Boulder batholith in Montana, finds that, although numerous samples from the same pluton may consist of similar mineral species, their relative proportions may be exceedingly variable. Modal analysis of chemically analyzed specimens from the granodiorite of Rader Creek, a pluton apparently homogeneous in outcrop and hand specimen, shows that several modes from a single specimen may be more variable than single modes from specimens from different localities. Furthermore, because he finds that the average composition of any particular specimen as determined from modes may differ from that as determined from its CIPW norm, Tilling concludes that norms and modes cannot always be used interchangeably as an indication of average composition.

Studies of mafic and ultramafic plutons

From a detailed study of the ultramafic zone of the Stillwater complex, Montana, E. D. Jackson (1–63) finds a strong lateral change in oxidation ratio in chromites that suggests that a lateral oxidation gradient persisted in the magma during crystallization and accumulation of that zone. He also notes a vertical decrease in total iron in chromites that indicates an early reversal in the expected trend of differentiation, later followed by normal iron enrichment.

T. P. Thayer (2–63) in a review of structures in alpine peridotite-gabbro complexes concludes that most layering, as well as lineation and foliation, in such complexes is formed by flowage of a semisolid crystal mush. The rarity of relict primary (stratiform) features implies that practically all the layering formed during emplacement, perhaps by mixing of predifferentiated rocks and partly by processes akin to metamorphic differentiation.

Studies by F. A. Mumpton, of Union Carbide Corp., with R. G. Coleman and P. B. Hostetler, reveal that the widespread occurrence of brucite in the New Idria, Calif., serpentine body is a product of early serpentinization and not of late hydrothermal alteration.

Studies of volcanic rocks and processes

Petrologic studies of the volcanic rocks surrounding the Creede caldera, San Juan Mountains, Colo., by J. C. Ratté and T. A. Steven (1–64) reveal a progressive increase in volume of lavas relative to ash flows that is interpreted as the result of progressive devolatilization of the Creede magma chamber. Cyclic changes in phenocryst composition and abundance and in chemistry through the sequence further record magmatic reversals that are attributed to interrupted differentiation and to stratification of the magma chamber. Similar changes in chemistry and phenocryst abundance have been noted by D. W. Peterson and R. J. Roberts for welded tuffs in Arizona and Nevada. Studies by R. L. Smith and R. A. Bailey, in progress on the Bandelier Tuff, Jemez Mountains, N. Mex., reveal progressive changes in emplacement temperature, chemistry, and feldspar composition which also contribute to the concept that many ash-flow deposits are the stratigraphically inverted products of zoned magma chambers.

Warren Hamilton (4–63) notes, on the basis of new chemical analyses of rhyolites from Yellowstone National Park, Wyo., that fluorine and chlorine are several times more abundant in lavas than in welded tuffs, and that iron, although about equally abundant in both rock types, is considerably more oxidized in welded tuffs. He suggests that the differences may aid in distinguishing lavas and welded tuffs.

David Cummings (1–64) has discovered that eddy zones associated with inclusions in rhyolite flows are a definitive criterion for determination of flow direction.

Study of the numerous mafic flows of Dome Mountain, Nev., within the moat of Timber Mountain caldera, by S. J. Luft (chapter D), indicates differentiation toward the upper flows. Upward decreases were observed in abundance of mafic minerals, color, index, and content of normative anorthite; increases were noted in content of alkalies and silica, K/Ca ratio, and differentiation index. The rocks are silica saturated. A Peacock index slightly below 56 puts the suite near the boundary of the alkalic-calcic and calc-alkalic fields.

Minor-element studies of igneous rocks and minerals

Investigation of the distribution of hafnium and zirconium in glassy rhyolitic volcanic rocks from the Jemez Mountains, N. Mex., is being carried on by David Gottfried. He finds that Hf/Zr ratios are greater in the glass than in associated zircon, and notes that although hafnium concentrations are higher in the zircon, a total amount of hafnium is greater in the glass, owing to the very small percentage of zircon in the rocks. A similar study by David Gottfried and C. L. Waring (p. B88–B91) on zircon from the southern California batholith shows a general increase in hafnium and Hf/Zr ratios from early gabbroic rocks to later granitic differentiates. The studies show that zircon crystallizes continuously throughout the course of magmatic differentiation and that it changes composition systematically as do the major rock-forming minerals.

Studies of thermal waters

New isotope data from the Salton Sea, Calif., geothermal area make an igneous origin for the saline brine less likely than previously thought.[79] Although the heat certainly is derived from a subjacent igneous body, oxygen and deuterium studies by Harmon Craig indicate a probable meteoric origin for the water of the brine. In addition, studies by Bruce Doe and Carl Hedge indicate that the isotopic composition of lead and strontium in the brine is similar to that in the enclosing sediments but quite unlike that in the Quaternary rhyolite domes in the area. (See also sections "Isotopic Tracer Studies," and "Light Metals and Industrial Minerals.")

A possible mode of origin for saline oil-field waters has been suggested by D. E. White. Many saline waters of sedimentary rocks probably owe their salinities and chemical characteristics to clay minerals that act as semipermeable membranes, permitting passage of water, some other charged molecules, and small, single charged cations (for example, Na^{+1}), but not anions or doubly charged cations (Ca^{+2} and Mg^{+2}). Chemical and electrical balance is maintained by return flow of hydrogen ions. Consideration of Ca/Cl and Br/Cl ratios versus salinity further provides a method of distinguishing waters produced by action of semipermeable clay membranes from those produced by dissolution of evaporites.

Studies of metamorphic rocks

A review of the mode of occurrence and the chemical and mineralogical variations of eclogites has led R. G. Coleman and D. E. Lee to the conclusion that the eclogite metamorphic facies is no longer a valid subdivision in terms of the facies concept. Classifying eclogites into three types on the basis of their occurrence in (1) kimberlites, basalts, and ultramafic rocks, (2) magmatite gneissic terranes, and (3) alpine orogenic belts, they find that group 3 eclogites have coexisting garnets and pyroxenes with Ca/Mg ratios suggesting pressure-temperature conditions characteristic of the glaucophane schist facies.

J. C. Reed (p. C69–C73) concludes from field relations and new chemical analyses that the greenstones of the Catoctin Formation in the Blue Ridge Mountains, Va., were probably derived from subareally deposited tholeiitic basalts. Their spilitic character, as indicated by Na_2O/K_2O ratios, is not due to submarine eruption, but rather to low-grade regional metamorphism.

[79] D. E. White, E. T. Anderson and D. K. Grubbs, 1963, Geothermal brine well—mile-deep drill hole may tap ore-bearing magmatic water and rocks undergoing metamorphism: Science, v. 139, no. 3558, p. 919–922.

Studies of sedimentary rocks

In a continuing study of the geochemistry and depositional environments of the Pierre Shale, H. A. Tourtelot, Claude Huffman, Jr., and L. F. Rader (1–64) have discovered positive linear correlations between cadmium and zinc, sulfur, and organic carbon. Some samples relatively high in cadmium do not contain organic carbon in amounts expected from this correlation, however, and they suggested that the cadmium concentration in the sea water, rather than the presence of organic matter, may be a controlling factor.

This conclusion is supported by facts that the minor-element composition of carbonaceous and noncarbonaceous nonmarine shales does not differ appreciably, and that in a very general way the minor-element content increases from nonmarine through nearshore to offshore shale facies. Consideration of the sorption properties of humic materials and clay minerals and differences in their behavior in dilute nonmarine solutions and relatively concentrated marine solutions suggests that interaction of these factors plays an important role in determining the final composition of the sediments.

Weathering of the Chattanooga Shale

Results of Fischer assay of samples of Chattanooga Shale collected from outcrops, drill cores, and other subsurface sources in Kentucky and Tennessee indicated that oxidation due to weathering leads to increased yields of water and decreased yields of oil according to Andrew Brown and I. A. Breger (p. C92–C95). Decrease in oil/water ratios when plotted against water yields provides an index for evaluating the degree of weathering of the shale; low ratios are indicative of a high degree of weathering.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

Applications of the computer to mineralogical calculations

A new computer program which greatly facilitates the refinement and indexing of X-ray powder diffraction data has been written and extensively tested by H. T. Evans, Jr., D. E. Appleman, and D. S. Handwerker (1–63). Starting with an initial approximation to the unit cell, the program computes the *d*-spacings, compares calculated and observed values, and assigns *hkl* indices to those observations which agree with the calculated values within a pre-set tolerance. The accepted set of indexed observations is then used in a least-squares refinement to obtain a new set of unit-cell parameters. The entire cycle is automatically repeated until the refinement converges on the unit-cell parameters which best fit the powder data. The program automatically excludes from the refinement those powder lines for which the indexing is ambiguous. Evaluation of precise unit-cell parameters by this means will enable mineralogists and petrologists to study a wide variety of new problems.

The Evans-Appleman-Handwerker program has been used with remarkable success by the Geological Survey to elucidate a large number of geologic problems, such as the nature of the alkali feldspars. From refined X-ray powder data, T. L. Wright (1–64), and P. M. Orville of Yale University, in collaboration with Geological Survey scientists, have developed calibrated curves from which the chemical composition and structural state of alkali feldspars can be independently determined. The curves are applicable to all undistorted sodium-potassium feldspars and are particularly useful for the study of the exsolution and inversion processes in potassic feldspars. Eventually it may be possible to specify equilibrium transitions from the study of natural feldspars through the use of refined unit-cell data.

D. B. Stewart (1–64) using the least-squares program has refined the unit-cell dimensions of four polymorphs of sodium feldspar from measurements collected up to 1140°C with an X-ray diffractometer. The relations between the polymorphs of this geologically abundant feldspar are now better understood, and the new determinations of the axial and volumetric thermal expansion will be very useful to geophysicists and ceramists, as well as to mineralogists and petrographers. The thermal expansion of a calcic labradorite of intermediate structural state was also measured to fill a gap in previously available data for the plagioclase series.

H. T. Evans, Jr., has continued his study on the valleriite ($CuFeS_2$) crystal structure problem and has reduced the many possible structure models to a few possibilities by a comprehensive computer analysis.

Changes in unit-cell parameters in spodumene and jadeite

The unit-cell dimensions and volumes of synthetic and natural spodumene and of jadeite have been determined by D. B. Stewart. Regular variations in the unit-cell parameters accompany the substitution of sodium for lithium. The extent of solid solution of sodium for lithium is at least 54 percent in synthetic spodumene, and at least 9 percent in natural spodumene. These results are useful in evaluating the grade of natural spodumene ores, and in determining the conditions under which spodumene forms in nature.

Application of electron diffraction power data to unit-cell calculations

In conjunction with the new least-squares program for refinement of X-ray powder data, Malcolm Ross has developed a theory and technique whereby electron diffraction powder data can also be used to evaluate unit-cell parameters to a precision of approximately 0.01 percent. The usefulness of electron diffraction data in the study of layer silicates, particularly the micas, has been demonstrated.

Chemical and physical properties of biotite

D. R. Wones has derived activities of the phlogopite and annite components in synthetic biotites composed of these two end members. The activities may be used in determining the effect of composition on the many reactions involving biotite. Several reactions have been established for the end members, so that the presence or absence of biotite in mineral assemblages can help to place restrictions on variables such as temperature, H_2O activity, O_2 activity, and S_2 activity during the formation of the assemblage in question. Such information is of interest in problems concerning magma formation and crystallization, metamorphism, ore deposition, and wallrock alteration.

D. R. Wones and Malcom Ross have determined the optical properties and unit-cell dimensions of a natural "oxybiotite" from the Jemez Mountains, N. Mex., both before and after heating in an atmosphere of hydrogen gas. Reduction of the natural material was found to decrease significantly the indices of refraction and to increase the values of unit-cell edges, particularly the *c*-dimension. The hydrogenation reaction is found to be reversible, for the reduced product can be easily oxidized in the solid state by passing argon gas over the biotite crystals. The oxidation-reduction reaction for a biotite of ideal composition is expressed as

$$KFe^{+2}Fe^{+3}_2(AlSi_3)O_{12} + H_2 \rightleftarrows KFe^{+2}_3(AlSi_3)O_{10}(OH)_2.$$

Malcolm Ross and D. R. Wones have found that the Jemez oxybiotite phenocrysts are not a single polytype but consist of approximately one-third 1-layer and one-third 2-layer forms. The remainder of the sample consists of more complex stacking polymorphs in which 3-, 14-, and 30-layer triclinic forms and 4-, 10-, and 20-layer monoclinic forms have been identified. A similar complex mixture of polytypes has been found in a number of other biotites from different localities. This work suggests that most biotites may be composed of a large variety of polytypes, and not of a single type as generally supposed.

Space-group symmetry of omphacite defined

The crystallography of a number of omphacite specimens has been studied by J. R. Clark and D. E. Appleman, who find that the space-group symmetry is $P2/m$, Pm, or $P2$—not $C2/c$ as had been expected by analogy to other pyroxenes such as jadeite. This supports the petrologic evidence that there is not a continuous solid-solution series between jadeite ($NaAlSi_2O_6$ and the omphacites.

Basal spacing in coexisting muscovite and paragonite as a measure of metamorphic grade

E-an Zen, in collaboration with A. L. Albee, of the California Institute of Technology, has measured the basal spacing of 42 pairs of coexisting muscovite and paragonite and has fitted the values to a straight line by least-squares methods. Use of this line to study rocks containing only one mica should yield estimates of the minimum metamorphic grade. A linear correlation between basal spacing and the composition of the analysed muscovite-paragonite samples has been made and will enable one to estimate the nature of the muscovite-paragonite binary solvus. A method has also been devised, based on X-ray intensity measurements, for calculating the composition of coexisting muscovite and paragonite in rocks where the minerals cannot be separated.

Nature of the phase transition in leucite

The phase transition in synthetic and natural leucite was investigated by G. T. Faust, using DTA methods. The inversion was found to be reversible but not isothermal. The data suggest either a transient polymorphic phase or an Al-Si order-disorder relation. The significance of the polymorphic inversion in petrogenetic theory was evaluated. The X-ray powder diffraction data for iron leucite, synthetic leucite, and six natural leucites were obtained and refined by the recently developed least-squares program.

Inversion relations of heulandite studied

A study of the thermal properties of the calcium-rich zeolite, heulandite, has been made by A. O. Shepard and H. C. Starkey (1–64). They find that this mineral normally inverts to heulandite B when heated to 250°C and is nearly destroyed at 500°C. After treatment of the natural material with KCl solution at 2 atmospheres and 118°C the sample could be heated to over 800°C before the structure was destroyed. These and other experiments indicate that potassium is an important factor in the thermal stability of certain zeolites.

Buddingtonite, first ammonium aluminosilicate found in nature

R. C. Erd, D. E. White, J. J. Fahey, and D. E. Lee have completed a study of buddingtonite, an ammonium analog of the alkali feldspars and the first ammonium aluminosilicate to be found in nature. The mineral occurs in Quaternary andesite and older rocks hydrothermally altered by ammonia-bearing hot-spring waters at the Sulphur Bank mine, Lake County, Calif. The mineral was first considered to be a zeolite because of the reversible dehydration-hydration below 370°C of the water as determined by chemical analysis. Buddingtonite chiefly occurs as compact masses psuedomorphous after plagioclase and associated with montmorillonite and sulfides of iron, antimony, and mercury. Chemical analysis gives a formula close to $NH_4AlSi_3O_8 \cdot \frac{1}{2} H_2O$.

Crystal structure of the borate, tunellite

In the continuing study of borate crystal chemistry, J. R. Clark (1–63) has solved the crystal structure of tunellite, $SrB_6O_9(OH)_2 \cdot 2H_2O$, and has shown it to be isostructural with the Ca analogue, nobleite. The structure contains infinite sheets composed of polymerized borate polyanions, with Sr^{+2} cations and water molecules filling available spaces in and near the sheets. The polymerized borate polyanions are composed of individual borate groups, each group containing three B–O tetrahedra and three B–O triangles. These polyhedra link at corners so that one oxygen is shared by all three tetrahedra. This is the first occurrence in any hydrated borate structure of one oxygen atom linked to three boron atoms. The crystal chemical principles proposed by C. L. Christ for formation of hydrated borate polyanions are confirmed.

Formula for lithiophorite calculated

Michael Fleischer and G. T. Faust (1–63) studied the manganese oxide mineral lithiophorite. By the use of various chemical, X-ray, and DTA techniques, reasonable chemical formulas were calculated for the complex spinel solid solutions obtained upon firing the lithiophorite samples.

Crystallography of rare-earth apatite, delrioite, and boltwoodite

The crystallography of several minerals, including a rare-earth apatite from New York containing 36.7 weight percent rare-earth oxides, delrioite ($CaO \cdot SrO \cdot V_2O_5 \cdot 3H_2O$) from Montrose County, Colo., and boltwoodite (a potassium-uranium silicate) from Live Oak County, Tex., has been determined by M. L. Lindberg.

Effect of temperature on glycolation of clays

Robert Schoen has studied the effect of high-temperature drying on the subsequent glycolation of the expanding clay minerals. The results indicate that exposure of a clay sample to an ethylene glycol atmosphere at 60°C for 1 hour is sufficient to effect complete glycolation regardless of previous drying temperature or drying medium.

New synthetic uranyl tricarbonate described

A new synthetic uranyl tricarbonate having the chemical formula $K_2Ca_3(UO_2)_2(CO_3)_6 \cdot 9-10H_2O$ has been described by Robert Meyrowitz, D. R. Ross, and Malcolm Ross. In the Green River Formation of Wyoming, Charles Milton and Robert Meyrowitz have found a green northupite containing as much as 8.7 weight percent FeO.

Relation of interplanar spacing to carbonate composition

A diagram useful for determining the composition of the carbonates within the system $MnCO_3-CaCO_3-MgCO_3$ has been prepared from published data by W. C. Prinz (p. C84–C85). The diagram shows the variation of the index of refraction and of the d_{211} interplanar spacing with chemical composition.

Second occurrence of cenosite described

A second United States occurrence of the rare yttrium-rich mineral cenosite has been discovered at Hall Mountain near Porthill, Idaho, by M. H. Staatz and J. W. Adams.

New refractive energies for CuO and Sc_2O_3

New specific refractive energy values have been determined for CuO ($k_{CuO}=0.173$) and for Sc_2O_3 ($k_{Sc_2O_3}=0.267$) by M. E. Mrose. These values give much better agreement between the calculated and measured indices of refraction than those published previously and will be useful in evaluating optical properties and chemical composition of the copper and scandium minerals.

EXPERIMENTAL GEOCHEMISTRY

Silicate-H_2O studies

R. O. Fournier and J. J. Rowe have measured the solubility of pure SiO_2 glass and gelatinous SiO_2 in H_2O at 1,000 bars pressure in the interval 120°C–420°C. At 124°C the solubility of SiO_2 glass is 613 parts per million, and at 357°C, 3550 ppm, and all intermediate values lie approximately on a straight line expressed by

$$-\log C=\frac{0.812}{T°K}-0.045,$$

where C is the concentration in moles per kilogram. Although the equation is not valid above 360°C, extrapolation to lower temperatures can be made with confidence.

Solutions in contact with glass had identical values of colorimetrically detectable and total dissolved silica, but solutions in contact with gelatinous SiO_2 gave colorimetric values identical with those obtained with glass, together with total SiO_2 measurements which were higher by 200 to 400 ppm.

Inconsistent and anomalousy high solubility values for quartz in H_2O–NaCl solutions have been reported by Kitahara,[80] using silver-lined vessels. Fournier and Rowe found that in gold-lined vessels 7 percent NaCl has little effect on the solubility of quartz. However, in silver-lined vessels the NaCl, H_2O, and Ag react to form silver chloride, hydrogen gas, and sodium hydroxide. The latter reacts with quartz to form sodium silicate, which accounts for the high values of solubility reported by Kitahara.

D. B. Stewart has determined the field of the gaseous water-rich phase that coexists with lithium aluminum silicates at 575°C and 2,000 bars. The gas that coexists with the range of the bulk compositions of lithium pegmatites contains 0.64 percent by weight of dissolved solids, mainly SiO_2. If all the dissolved solids are precipiated from the gas, the amount of quartz by weight would be 7 to 11 times greater than the amount of lithium silicate, depending on the particular lithium mineral formed. As the melting of such a mixture of solids, even in the presence of saturated steam at 2,000 bars and small amounts of feldspar, requires the geologically improbable temperature of 1,000°C, such zones reported from lithium pegmatite could only have been formed by deposition from a gaseous phase.

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[80] S. Kitahara, 1960, The solubility of quartz in the aqueous NaCl solution at high temperatures and high pressures: Rev. Phys. Chemistry of Japan, v. 30, p. 115–121.

The solubility of H_2O in obsidian at 2,000 bars fluid pressure was determined by H. R. Shaw to be 6.5 weight percent at 750°C and 5.9 weight percent at 850°C. The decrease of approximately 0.5 percent H_2O by weight per 100°C increase in temperature at constant fluid pressure is nearly the same as that found by Goranson [81] for the system albite-H_2O.

J. J. Hemley has studied phase relations in the system Na_2O–K_2O–Al_2O_3–SiO_2–H_2O in an aqueous chloride environment at 400°C–500°C and 1,000 bars. The compositions of the aqueous phase that characterizes equilibrium between various mineral assemblages in this system aid in the understanding of compositions required for natural solutions or emanations that produce metasomatic changes in rocks. These changes are a significant aspect of granitic rock emplacement and differentiation, pegmatite formation, contact metamorphism, and the rock alteration associated with many ore deposits.

Ion-exchange phenomena

As part of a continuing theoretical study of ion-exchange selectivity, A. H. Truesdell (1–64) has predicted the orders of selectivity among the alkaline-earth cations from energy calculations on model systems. The model that corresponds most closely to real exchangers consists of paired -1 sites with variable equivalent anionic radius and variable separation. Model and real systems correspond in (1) that for model systems of less than 5Å site separation, divalent ions generally are preferred to monovalent ions, whereas -2 site models show a preference for monovalent ions; and (2) that the orders of selectivity calculated from the model system agrees with experiments on real exchangers. The following selectivity orders were calculated using $+1$ sites separated by 4.5Å and increasing the effective anionic radius: ion exchange material exhibiting the particular order is also given:

Increasing effective anionic radius ↓	Order (decreasing preference)		Natural Exchanger
	I	Mg Ca Sr Ba	Kaolinite, beidellite (2d site)
	II	Mg Sr Ca Ba	Silica gel, illite
	III	Mg Sr Ba Ca	Silica gel, illite
	IV	Mg Ba Sr Ca	Kaolinite
	V	Ba Mg Sr Ca	Biotite, Kaolinite; Na alumino-boro-silicate glasses
	VI	Ba Sr Mg Ca	Montmorillonite, silicate glasses, feldspar, K-mica, bentonite, permutite, phosphate glass, resin, beidellite (1st site)
	VII	Ba Sr Ca Mg	Montmorillonite, silicate glasses, feldspar, K-mica, bentonite, permutite, phosphate glass, resin, beidellite (1st site)

From clay titration data, Marshall [82] found that beidellite exhibits two orders of selectivity, VII at low pH, and I at high pH. The second site with a small equivalent anionic radius behaves as a weak acid, whereas the first site with a larger anionic radius behaves as a stronger acid.

Christ and Truesdell (1–64) have developed a method for the interpretation of clay titration curves. Garrels and Christ [83] and P. D. Blackmon [84] have shown that if each H clay is considered a mixture of two distinct weak acids, then for an exchange,

where X is the clay substitute, the equilibrium constant is

$$HX + M^{+1} = MX + H^{+1}, \tag{1}$$

$$K_{HM} = \frac{[H^{+1}][MX]}{[M^{+1}][HX]} \tag{2}$$

where [ ] denotes activity. In order to obtain values for ${}_1K_{HM}$ and ${}_2K_{HM}$, certain assumptions based on unsatisfactory theory were made in the evaluation of the ratio $[MX]/[HX]$. However, if the exchangeable cations form a regular solution on a clay, then (2) may be rewritten as

$$K_{HM} = \frac{[H^{+1}](MX)}{[M^{+1}](HX)} \exp - \frac{W_{HM}}{RT}(1 - 2N_{HX}), \tag{3}$$

where (MX) and (HX) are concentrations in the binary solution on the clay, W_{HM} is a constant for a given clay and a given exchange, and N_{HX} is the mole fraction of H clay remaining. These variables are readily evaluated from experimental data, and no unverified assumptions need to be made. Using the data of Marshall and others [85] [86] the following numerical constants have been obtained from (3):

H clay	M^{+1}	${}_1W_{HM}$	${}_2W_{HM}$	${}_1K_{HM}$	${}_2K_{HM}$
H beidellite	Na^{+1}	−0.28	−1.5	$10^{-3.1}$	$10^{-7.2}$
	K^{+1}	−0.65	0	$10^{-2.4}$	$10^{-6.6}$
	NH_4^{+1}	−0.30	0	$10^{-2.5}$	$10^{-7.1}$
H illite	Na^{+1}	−.035	−0.79	$10^{-2.9}$	$10^{-6.4}$
	K^{+1}	−0.74	−1.13	$10^{-2.0}$	$10^{-5.2}$
	NH_4^{+1}	−0.61	0.10	$10^{-2.2}$	$10^{-5.9}$
H kaolinite	Na^{+1}	0.35	0	$10^{-4.1}$	$10^{-5.9}$
	K^{+1}	0	0	$10^{-1.7}$	$10^{-3.0}$
H bentonite	K^{+1}	−1.2	------	$10^{-2.0}$	------

[81] R. W. Goranson, 1936, Silicate-water systems; the solubility of water in albite-melt: Am. Geophys. Union Trans., v. 17, p. 257–259.

[82] C. E. Marshall, 1954 Multifunctional ionization as illustrated by the clay minerals, *in* Proceedings 2d National Clay Conference: Natl. Acad. Sci.-Nat. Resources Council Pub. 327, p. 364–384.

[83] R. M. Garrels and C. L. Christ, 1956, Application of cation-exchange reactions to the beidellite of the Putnam silt loam soil: Am. Jour. Sci., v. 254, p. 372–379.

[84] P. D. Blackmon, 1958, Neutralization curves and the formulation of monovalent cation exchange properties of clay minerals: Am. Jour. Sci., v. 256, p. 733–743.

[85] C. E. Marshall and W. E. Bergman, 1942, The electrochemical properties of mineral membrane: Jour. Phys. Chemistry, v. 46, p. 52–61.

[86] C. E. Marshall and C. A. Krinbill, 1942, The clays as colloidal electrolytes: Jour. Phys. Chemistry, v. 46, p. 1077–1090.

Truesdell and A. M. Pommer (1–63) have investigated the alkaline-earth ionic selectivity of a phosphate glass as part of a general study of electrode properties. The composition of the glass is (in weight percent): SiO_2, 3.1; Al_2O_3, 5.6; total iron as Fe_2O_3, 16.0; Na_2O, 6.1; K_2O, 0.09; H_2O, 0.19; P_2O_5, 66.7; and the order of selectivity is $2H^{+1} > Ba^{+2} > Sr^{+2} > Ca^{+2} > 2K^{+1} > 2Na^{+1} > Mg^{+2}$.

The use of electrodes in field measurements of Na^{+1} in lacustrine closed basins in California and Oregon was accomplished by Truesdell, B. F. Jones, and A. S. Van Denburgh. These waters range from 10 to 120,000 parts per million Na^{+1} and contain variable amounts and ratios of Cl^{-1}, CO_3^{-2}, HCO_3^{-1} and SO_4^{-2}. The Na^{+1} concentrations are obtained from Na^{+1} activities by means of a dilution technique and agree well with flame photometric measurements.

Variation in H_2O and CO_2 activities in Searles Lake, Calif.

H. P. Eugster, of Johns Hopkins University, and G. I. Smith have investigated the relation between the chemical activities of H_2O and CO_2 in the brines of Searles Lake and the evaporite minerals that are in contact with those brines. Fifteen of the 21 known evaporite minerals can be considered as simultaneous and occupy 28 different $a_{H_2O}=a_{CO_2}$ fields. All observed suites (several thousand) are in agreement and show both stratigraphic and lateral independent variations in a_{H_2O} and a_{CO_2} values which reflect either depositional conditions or postdepositional events.

Gypsum-anhydrite equilibria

E-an Zen, in an extended laboratory and theoretical study of the system $CaSO_4$–NaCl–H_2O, has reexamined the available thermochemical data, including more recent heat-capacity data for anhydrite ($CaSO_4$), and revised the temperature of the gypsum-anhydrite—H_2O assemblage from 40°C to 46°C at 1 atmosphere pressure. The change of 6°C is significant in terms of evaporite precipitation from sea water, and makes the precipitation of anhydrite from sea water an unlikely event even if equilibrium conditions were realized.

In the laboratory, Zen has been unable to crystallize anhydrite from aqueous solutions containing variable amounts of NaCl at 35°, 50°, and 70°C; although he was able to precipitate it from a saturated $CaCl_2$ solution at 70°C. At temperatures where anhydrite should be stable, it converts to gypsum in 3 months, although in runs of 18 months, no gypsum formed, and the anhydrite appeared to be recrystallized. The preparation of starting materials, identification of products, seeding, length of runs, and approaches to reversibility influence the results, and much existing experimental work on the system is internally inconsistent. The precipitation of anhydrite is apparently controlled in part by kinetics, and the origin of sedimentary anhydrite beds remains open to question.

Studies of time-dependent processes

H. R. Shaw has measured viscosities of synthetically hydrated obsidian, using the falling-sphere technique, at pressures of 1,000 and 2,000 bars and temperatures between 700°C and 900°C. The effect of pressure on the viscosity is found to be so slight that the results can be expressed as a function of H_2O content and temperature alone. At 4.3 percent H_2O, by weight, the common logarithm of the viscosity, in poises, ranges from 6.51 at 800° to 5.88 at 900°C, and at 6.2 percent H_2O from 6.54 at 700°C to 5.25 at 850°C. These data and the data of Friedman, Long, and Smith (2–63) on rhyolite glass, at H_2O contents of as much as 1.25 percent have been interpreted in the light of the discrete-ion theory of silicate melts,[87] and a generalized graph has been constructed which permits approximate predictions of viscosities of framework silicate H_2O melts for H_2O contents to about 10 percent by weight at temperatures between 500°C and 1200°C (H.R. Shaw 1–63).

Shaw has also measured the rate at which H_2O is absorbed by obsidian at 850°C and 2,000 bars fluid pressure. A linear relation between weight increase of obsidian, due to sorption, and the square root of time was found to hold until the obsidian is more than two-thirds saturated. Extrapolation to vanishing time gives an intercept at an H_2O content between 1.5 and 2.0 percent by weight (saturation under these conditions is 5.9 ± 0.2 percent). This demonstrates that there is some mechanism of rapid hydration near the surface of the sample before the slower diffusion-controlled mechanism of hydration takes place. Using the intercept at vanishing time as the initial H_2O content, the average diffusion coefficient under these conditions was determined to lie between 10^{-7} and 10^{-8} $cm^2 sec^{-1}$.

B. J. Skinner has demonstrated that the monotropic inversion pyrite → marcasite is a zero-order kinetic reaction at 1 atmosphere pressure, between 300°C and 500°C. The host marcasite phase acts as a template for the orientation of the daughter pyrite phase, and experiments are proceeding to establish the crystallographic relations of this epitaxic relation.

[87] J. D. Mackenzie, 1957, The discrete ion theory and viscous flow in liquid silicates: Faraday Soc., Trans., v. 53, p. 1488–1493.

Simple systems have been selected for study to further elucidate kinetic mechanisms controlling polymorphic inversions in ore minerals. Two such systems presently under study are α-domeykite (Cu_3As) → algodonite ($Cu_{(8-x)}As$ + β-domeykite ($Cu_{(3-x)}As$) in the temperature range 115°C–250°C, and dense tetragonal Cu_2S→ chalcocite in the temperature range 25°C to 100°C and over the pressure range of 1 to 2,000 atmospheres.

Thermodynamic properties

R. A. Robie has constructed and placed in routine operation a vacuum-jacketed hydrofluoric acid solution calorimeter having very low thermal leakage. From it has been obtained a heat of solution of KCl in water at 25°C and infinite dilution of 4,116±11 calories, within 0.05 percent of the most accurate determinations by other laboratories. Reproducible preliminary results have been obtained with $KAlSi_3O_8$ (microcline) in 20-percent HF at 60°C.

Fluid inclusions

Edwin Roedder, in a continuing study of fluid inclusions, has found that liquid CO_2 inclusions commonly occur in the olivine and other minerals of olivine nodules in alkali basalts. The inclusions apparently represent droplets of a dense CO_2 phase, immiscible with the magma, trapped by the growing crystals at a depth of 8–16 kilometers. Their existence implies that the olivine crystals can withstand tensile stresses of 70,000 pounds per square inch at 1,200°C.

Roedder has also observed the metastable persistence of ice at 6°C for as long as 1 hour in a liquid inclusion frozen in the laboratory. Failure of a gas phase to nucleate in the liquid results in a high negative pressure for the assemblage of ice and water.

The application of small thermal gradients to fluid inclusions causes rapid non-Brownian movement of vapor bubbles in the inclusions and is the basis of a U.S. patent application for a thermal-gradient sensing device.

Roedder and R. L. Smith have found that the minute closed vesicles in pumice, which are practically vacuums after first cooling to surface temperature, gradually become filled with liquid water after hydration of the surrounding glass takes place. Ninety-one air-dried samples of many pumice types were assigned to three categories on the basis of visual estimates of vehicle water: 0, <10, and >10 percent H_2O. When the known or estimated geologic age of the samples in each category was examined, 81 of the 91 samples agreed with the following tabulation:

Percent H_2O	*Age, in years*
0	$<10^4$
<10	10^4–10^6
>10	$>10^6$

There are many uncontrolled variables that make further refinement as an "age method" doubtful, and even preclude its use in some localities, but the method is quick and simple and applicable to time spans difficult to measure by other geochronological techniques.

GEOCHEMICAL DATA

The collection and synthesis of geochemical data are important parts of the program of the Geological Survey. Some types of collections, such as the "Data of Geochemistry" are of immediate value as reference works, not only to geologists but to workers in other scientific fields as well. Other collections, commonly those resulting from fieldwork, provide background for studies of geologic processes, environmental effects on animal and human health, or for programs in economic geology such as geochemical prospecting.

Uranium and thorium in igneous rocks

Z. E. Peterman has completed a draft report on the geochemistry of uranium and thorium in igneous rocks. Of interest are the uranium and thorium contents of the major classes of nonalkalic igneous rocks. These are median values based on nearly 1,000 uranium analyses representing almost 7,000 samples, and approximately 500 thorium analyses representing almost 3,000 samples. The following estimates are made: mafic igneous rocks (gabbros and basalts), 0.5 parts per million uranium and 1.6 ppm thorium; diorites and quartz diorites, 1.7 ppm uranium and 7.0 ppm thorium; granodiorites, 2.3 ppm uranium and 9.0 ppm thorium; granites and quartz monzonites and fine-grained equivalents, 3.9 ppm uranium and 16 ppm thorium.

Estimates for the exposed continental crust are 2.4 ppm uranium and 10 ppm thorium. Assuming a basaltic oceanic crust, and a basaltic layer beneath the continental crust, the uranium and thorium contents of the total earth crust are estimated to be 1.5 ppm uranium and 5.8 ppm thorium. The major uncertainty in these estimates is the poor knowledge of the relative abundance of igneous rock types in the crust.

Minor-element contents of Paleozoic black shales

Beds of metal-rich black shale, characterized by concentration of at least 500 parts per million vanadium, and variable concentrations of barium, boron, chromium, copper, lanthanum, molybdenum, nickel, lead, silver, yttrium, and zinc are now known from formations in every system of the Paleozoic at one or more localities in the conterminous United States. J. D. Vine has assembled data that indicates that these beds were deposited in geologic environments ranging from the abyssal sea waters of the western eugeosyncline to transgressive brackish-water beds that overlie coal in the Eastern Interior coal cyclothems, and the black-shale facies associated with evaporite deposits.

Ordovician graptolitic black shale marginal to and within the western eugeosyncline is locally metal rich at widely scattered localities extending from Mono County, Calif., and Esmeralda County, Nev., on the south, to British Columbia on the north, and including localities in central and northern Nevada, central Idaho, and northeastern Washington.

Fluorine content of silicic volcanic glass

R. R. Coats, W. D. Goss, and L. F. Rader have found in an investigation of more than 170 samples of silicic glassy volcanic rocks a marked regional variation in fluorine content. Fluorine content of the samples ranges from 20 to 4,900 parts per million; the median value is 520 ppm, and the 90th percentile is 1,820 ppm. The frequency distribution of fluorine contents closely approaches a log-normal one.

The highest values are predominantly from a belt in central Colorado, and west-central New Mexico, from the Big Bend region of Texas, and from southeastern Idaho, western Utah, and northeastern Nevada. The distribution of fluorine in the rocks corresponds closely with the distribution of fluorspar deposits, and somewhat less closely with areas where volcanic rocks are prevalent, and where ground waters carry large amounts of fluorine.

Minor elements in metallic ore minerals

M. S. Toulmin has completed compilation of 2,800 published analyses of minor elements in sulfide and other metallic ore minerals on punch cards, together with geologic and geographic data of mineral occurrence.

Analysis of spectrographic data on Entrada Sandstone

P. L. Williams has continued study of the Entrada Sandstone in the Moab 1:250,000 quadrangle, Colorado and Utah, and has had a statistical analysis of spectrographic data on Entrada samples made by the Geological Survey computer. The analysis shows that elemental abundance is about the same in altered and unaltered rock. This is interpreted to mean, in the absence of sample bias, that some minerals were destroyed during alteration. The data further indicate that their chemical constitutents were not removed, but formed new minerals or were sorbed in remaining minerals.

For example, barium is about four times as abundant in the heavy minerals of altered sandstone as it is in heavy minerals in unaltered sandstone. This suggests that barium possibly was originally present in cement, or was sorbed in the clay fraction of unaltered sandstone recrystallized during alteration into larger grains of barite. Aluminum, sodium, nickel, lead, yttrium and ytterbium, silver, beryllium, cobalt, molybdenum, columbium, lithium, scandium, uranium, and vanadium are more abundant in altered sandstone than in unaltered standstone.

Manganese nodules from sea show high tellurium content

D. F. Davidson and H. W. Lakin report that tellurium is much more abundant in manganese oxide nodules from the ocean floor than in other types of manganese oxide occurrence. Highest content of tellurium, as much as 125 parts per million Te, was found in nodules from the Pacific Ocean. These nodules are the first discovered point of strong concentration of tellurium in the sedimentary cycle so far as is known.

Computer simulation applied to sampling methods and data analysis

A. T. Miesch and J. J. Connor (1–64) in cooperation with R. N. Eicher have been investigating methods of sampling and data analysis using the technique of computer simulation. A computer program has been devised which enables one to "sample" mathematical models of rock bodies using various sampling schemes, and then to analyze the sample data in order to recover the built-in parameters of the model. The advantage of this approach is chiefly in the fact that the parameters are known, whereas in field problems, one can seldom be certain of the accuracy of his statistical estimates. A two-stage method of sampling in geochemical prospecting has been proposed on the basis of studies of this type.

GEOCHEMISTRY OF WATER

Investigations of the geochemistry of water by the U.S. Geological Survey are directed mainly toward understanding the interrelations of the chemical character of water to the geologic and hydrologic environment. Some of the topics under study include the source of dissolved constituents in precipitation, the chemical content of stream waters, the relation of the chemistry of ground waters to the mineralogy of aquifers, the effects of local hydrology on the chemistry of lake sediments, and the use of isotopes in hydrologic investigations. Studies of thermal waters are treated in the sections "Light Metals and Industrial Minerals," "Field Studies in Petrology and Geochemistry," and "Isotopic Tracer Studies."

STUDIES OF ATMOSPHERIC PRECIPITATION

Chemical composition of precipitation

Utilizing the precipitation sampling network established in the summer of 1962, A. W. Gambell, Jr., has obtained detailed data for a complete year on the chemical composition of rainfall over a 34,000-square-mile area in North Carolina and Virginia. Over the network as a whole, month-to-month variation in rainfall composition appears to follow seasonal patterns. An increased oceanic influence during the winter months was evident. The range of monthly average concentrations for some of the individual constituents is as follows: SO_4^{-2}, 1.1 part per million to 3.2 ppm; Cl^{-1}, 0.1 ppm to 1.2 ppm; Ca^{+2}, 0.2 ppm to 1.2 ppm.

Studies by A. W. Gambell, Jr., and D. W. Fisher at Prince William National Forest Park, Va., suggest that much of the SO_4^{-2} in rainfall results from the catalytic oxidation of SO_2 in cloud droplets. Atmospheric NO_2 is indicated as an important catalyst in this reaction. Samples from a number of thunderstorms suggest that, contrary to widespread belief, lightning is relatively unimportant as a source of NO_3^{-2} in thunderstorm rainfall.

Tritium in precipitation and stream water

Tritium rainout has increased considerably since the first nuclear bombs were exploded in 1952, and, due to weather phenomena, a tritium rainout peak occurs sometime during the spring and early summer period. G. L. Stewart, C. M. Hoffman, and T. A. Wyerman observed particularly sharp increases in tritium rainout during late spring and early summer of 1963 when tritium levels in precipitation reached about 7,000 tritium units at Palmer, Alaska, 4,100 T.U. at Lincoln, Nebr., and 1,700 T.U. at Menlo Park, Calif. Other sample collection stations showed similar increases. The same sharp increase in tritium level has occurred in stream water. In 1962, some stream-water samples had peak values of 300 T.U., compared to tritium levels for these same streams of over 2,000 T.U. during the summer of 1963.

STUDIES OF SPRINGS, STREAMS, AND LAKES

Thermal springs in Upper Colorado River basin

In the Upper Colorado River basin, thermal springs discharge to the streams about 59,100 acre-feet of water and 541,600 tons of dissolved solids annually, according to the calculation of W. V. Ioms, C. H. Hembree, and G. L. Oakland. Hot springs along the 17-mile reach of the Colorado River between the Eagle River and the Shoshone powerplant in Colorado contribute about 182,600 tons of dissolved solids to the river each year; of this, about 160,700 tons is sodium chloride. Computations show that thermal springs along the banks and in the bed of the Colorado River between the Shoshone powerplant and Cameo, Colo., add an additional 252,000 tons of sodium chloride annually.

Uranium in stream water

In a study of the quantity of radioelements being transported by surface waters, E. C. Mallory has calculated that the minimal load of uranium contributed yearly by major rivers of the conterminous United States to the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean is 58,000, 771,000, and 361,000 pounds, respectively.

GROUND-WATER STUDIES

Methane gas in a fresh-water aquifer in Louisiana

Studies by A. L. Hodges, Jr., S. M. Rogers, and A. H. Harder (1–63) of salt-water encroachment in the Chicot aquifer in the heavily pumped Lake Charles area in southwestern Louisiana have revealed the presence of methane gas in the water in some localities. Techniques developed there for estimating the quantity of gas and the rate of movement of the gaseous water can be used elsewhere. There appears to be no relation between gas content and high chloride content.

Freeze-thaw effects on chemistry of ground water

In northwestern Alaska, marked increases in mineralization of ground water during the colder months are accounted for by simple concentration by freezing, and by reduction in recharge of low mineral content during winter, according to A. J. Feulner and R. G. Schupp (3–63).

Fluoride in Florida ground water

Mapping of the natural fluoride content of ground water in Florida by L. G. Toler shows concentrations as high as 13 parts per million in coastal areas of the

Florida panhandle. Insoluble residues of well cuttings from limestones in peninsular Florida disclose previously unreported fluorite at depths which coincide with zones of high fluoride content in ground water. Other known minerals in Florida that contain fluoride are phosphate minerals and mica.

Arsenic-rich ground water in Oregon

Work by A. S. Van Denburgh has helped to delineate the areal extent, probable geologic associations, and geochemical character of arsenic-rich ground water in central Cane County, western Oregon. The water that contains appreciable arsenic—as much as 1.6 parts per million—apparently is restricted to aquifers within the Fisher Formation, an accumulation of pyroclastic debris of Eocene and Oligocene age. Sodium and bicarbonate are the principal dissolved constituents; the calcium and magnesium contents are characteristically low; the boron and orthophosphate contents are unusually high for Oregon ground waters.

Arsenic and boron probably were trace components of the airborne volcanic debris that accumulated to form rocks of the Fisher Formation. After deposition, the glassy portions and certain mineral constituents of the debris were altered hydrochemically and converted to clays and, perhaps, to zeolites. The resulting interstitial water probably was naturally softened and was alkaline. It evidently contained arsenic and boron extracted from the glassy volcanic debris during the course of the same diagenetic reactions that produced the mineralogic changes.

CHEMICAL EQUILIBRIUM STUDIES

Geochemistry of closed lacustrine basins

Study of layered salt crusts at Deep Spring Lake, Calif., by B. F. Jones (1–64) has shown that in spite of bulk chemical differences the saline minerals follow the same sequence, from bottom to top, of nahcolite, thenardite, burkeite, trona, halite, in both the main playa and a nearby fault-trough pond. Thenardite is dominant on the playa, while trona is dominant in the pond. The mineral layering reflects the original sequence of precipitation, adjustments to local equilibrium with interstitial solutions, and an upward decrease of the pressure of CO_2.

Examination of the clay fractions from alluvial-fan materials, former beach deposits, and modern playa sediments in Deep Spring Valley suggests that expandable-lattice clays have undergone alteration in contact with the waters of an alkaline lake, which is related to the increase in salinity accompanying the evaporative recession of the lake.

Dehydration of gypsum in Na_2SO_4 solution

Experiments by L. A. Hardie in the system Na_2SO_4–$CaSO_4$–H_2O have determined reversibly the dehydration of gypsum to anhydrite in saturated Na_2SO_4 solution at $47° \pm 2°C$ with approximately 12-month runs. This can be extrapolated to about 50° C in pure $CaSO_4$ solutions, as compared to $46° \pm 25°$ C calculated from the most recent thermodynamic data of Kelley (1960). A system has been devised for measurement of the activity of water reproducibly to 0.005, and solid-phase transition temperatures are being studied utilizing the method. Five double salts have been found in the ternary system, all metastable with respect to glauberite ($Na_2SO_4 \cdot CaSO_4$) above 25° C; at least one has been found in the efflorescenses in Saline Valley, Calif.

Mechanism of acid generation in coal-mining areas

Ivan Barnes and F. E. Clarke (3–64) reported on an early phase of a fundamental study of water chemistry in relation to generation of acid mine wastes and other contaminants. They inferred that reactions between water, rock minerals, and organic matter result in an acid, strongly reduced solution containing iron and sulfate. These reactions may be able to take place in an anaerobic environment, and, as a result, could have an important bearing on methods selected for preventing or controlling generation of acid mine wastes.

Manganese concentrations in water

J. D. Hem (1–64) has found that manganese is adsorbed somewhat more strongly than calcium on the surfaces of feldspar grains. The concentration of manganese in ground water could be altered by changes in adsorption equilibria accompanying changes in concentration of predominant dissolved cations. A study by E. T. Oborn (1–64) showed that aquatic vegetation in general contained larger percentages of manganese than did land plants.

Very dilute solutions of gallic acid can bring manganese into solution from manganese dioxide, and such solutions are relatively stable in contact with air. The dissolved manganese is in a reduced form but is not fully complexed with organic molecules.

ISOTOPIC STUDIES IN HYDROLOGY

Preparation of water samples for C^{14} analysis

A simple system for the field preparation of water samples for C^{14} analysis has been devised by H. R. Feltz and B. B. Hanshaw (1–63) and tested under field conditions. By use of this technique the total dissolved carbonate species can be stripped from a large water sample and reduced to a small volume.

Source of salt-water contamination at Brunswick, Ga.

A study of saline water contaminating ground water at Brunswick, Ga., was made by B. B. Hanshaw, William Back, and Meyer Rubin (1–64). C^{14} analysis indicated that the contaminant was ancient ground water and not nearby modern ocean water.

Tritium fractionation in porous media

Because the physical and chemical properties are different for the various hydrogen and oxygen isotopes, observations of isotopic fractionation may lead to quantitative techniques for ascertaining processes that occur in nature. Laboratory investigations conducted by G. L. Stewart, C. M. Hoffman, and T. A. Wyerman show that tritium fractionation occurs during the diffusion of water through porous materials. Tritiated water held at low tensions (saturated conditions) contained about 15 percent more tritium than water held at 35 atmospheres tension.

INVESTIGATIONS AT THE HAWAIIAN VOLCANO OBSERVATORY

Volcanic events, 1963

Tiltmeter surveys indicated a rapid buildup of magma within the summit complex during March and April. Discharge of magma into the Koae-southwest rift systems followed during May 9–11. This discharge was accompanied (1) by many earthquakes that could be felt, (2) by much harmonic tremor centering about the junction of the two rift systems, and (3) by the opening of a larger number of cracks in a zone about 3 miles long and as much as a quarter mile wide. Coincidentally, the tiltmeters indicated rapid collapse of the summit area and inflation under the rift zone centered on the area of seismic and crack activity.

The cycle reversed on May 12, when the tilt-instrument system indicated a rapid resumption of inflation under the summit that continued until June 30. Violent seismic activity that centered along the upper east rift zone of Kilauea began on July 1 and initiated a new period of deflation. Later, a new zone of cracks developed for a distance of about 4 miles, trending N 60°–70° E to a point in the area of Devil's Throat and Aloi crater. Long-base tiltmeter readings and precise levelling indicated an absolute uplift in the center of the zone of almost 3 feet, coupled with downdrop along the margins of nearly half a foot. Coincident rapid detumescence of the Kilauea summit region approximately equalled that which accompanied the December 1962 eruption near Aloi crater.

A rapid return to summit inflation was interrupted by outpouring of a million cubic yards of lava at Alae pit crater on the upper east rift zone during August 21–23. An estimated maximum rate of extrusion of 150 cubic yards an hour was reached in the 4th hour of activity. The laval lake reached its maximum thickness in 12 hours of activity. Though some fountaining continued for another 36 hours, the level of the lake actually receded, presumably as a result of drain and (or) degassing back. Beginning 4 days after the close of eruption, the volcano observatory staff began a systematic study of the cooling history of the Alae lava lake.

Six weeks later, on October 5, about 10 million cubic yards of lava poured from the floor of Napau pit crater several miles farther east along the same rift zone. Eruption was accompanied by marked deflation of the Kilauea summit, by shallow quakes and strong harmonic tremor, and by a particularly sharply felt earthquake which probably signalled the actual opening of the Napau rift. About 8 hours later, additional outbreaks took place to the east, 3 to 6 miles farther down the rift zone, but from the glow under the heavy rain clouds it appeared that most activity had ceased by 4 a.m. on October 6. This October activity completely erased all the inflation gained earlier in the year.

Studies in Alae lava lake

The eruption of August 21–23, 1963, left a lava lake of olivine-poor tholeiitic basalt 800 feet wide by 1,000 feet long and as much as 50 feet deep in the bottom of Alae pit crater. Field studies of the cooling lava lake will provide data supplemental to that being obtained from the larger, deeper Kilauea Iki lake. The studies include (1) periodic surface mapping to follow changes in crack pattern and sublimate deposition; (2) repeated surface leveling; (3) periodic observations, on a close net, of the intensity of vertical component of magnetic field; and (4) repeated core drilling for sampling and temperature measurement, starting with a crust thickness of only 3.4 feet. The temperature at the base of the crystalline crust was found to be 1067°C at Alae, compared with 1065°C at Kilauea Iki, and the rate of crustal thickening is similar in both lava lakes (D. L. Peck and others, chapter D). The maximum temperature at Alae, 1135°C, was measured 7.6 feet below the base of the crust. Fountain temperatures did not exceed 1140°C.

The surface of the lava lake first fell at a rate of 0.50 foot per month, but thereafter it began a slow steady rise at rates ranging from 0.05 to 0.08 foot per month, presumably because of vesiculation of the lava caused by exsolution of gas. Since late September 1963 the edge of the lake has risen at a moderate rate, and the doughnut-shaped area between the center and edge has risen at a higher rate.

Vertical magnetic-intensity measurements at 25 stations showed an elongate magnetic high that is parallel to, but slightly south of, the east-west centerline of the lake and that increased in amplitude by as much as 600 gammas from September 11, 1963, to January 28, 1964. Apparently the position of the anomaly is controlled by the extreme topographic relief of Alae crater; also, its changing amplitude reflects the thickening of the magnetic crust on the lava lake.

Petrology of submarine basalts in southeastern Hawaii

In October 1962, dredge samples of submarine lava were collected from depths of 1,400 to 17,000 feet along the submerged part of the east rift zone of Kilauea Volcano and from seamounts near the island of Hawaii. Chemical and petrographic study of these unique samples by J. G. Moore shows a systematic change in the character of the vesicles, whose volume and size decrease with depth. These changes can provide a scale by which the depth of eruption of ancient lavas may be estimated.

The glassy crust of the east rift zone lavas is closely similar in chemical composition to the more highly crystallized interior of the flows and also to subaerial lava flows of the same rift zone. This indicates that chemical exchange does not take place between sea water and the surface of the deep-sea basalt at the time of eruption. In the material studied there is no evidence that spilite forms at the time of extrusion of submarine lavas.

Magmatic differentiation at Kilauea

Chemical and mineralogic studies by K. J. Murata and D. H. Richter on lavas of the 1959–60 eruption of Kilauea Volcano point to the involvement of three different magmas. The 1959 summit magma, representing the earliest stage of differentiation, was characterized by the crystallization and gravitative separation of olivine. During the early part of the 1960 flank eruption, a more differentiated magma, probably remnant from the 1955 flank eruption, was expelled. Its differentiation was controlled by separation of plagioclase, clinopyroxene, and olivine. Later, during the 1960 flank eruption, magma separating only clinopyroxene and olivine was erupted. The lavas abundantly illustrate the mechanism of fractional crystallization for differentiation of basaltic magmas as long propounded by N. L. Bowen.

Large submarine landslides on Hawaiian Ridge

A large area of irregular topography on the slope of the Hawaiian Ridge is interpreted by J. G. Moore (chapter D) as submarine landsliding on a large scale. He describes 2 slides 50 kilometers long that moved down a slope having an overall gradient of about 2°. A concave escarpment marks the head of the slides, and flat-topped tilted blocky seamounts occur on the middle and lower parts.

United States–Japan cooperative program

A team of seismologists with portable equipment, from Japan, under the leadership of Professor Minakami, head of the Earthquake Research Institute, Tokyo University, spent 6 months recording earthquakes, artificial shots, and eruption tremors from different triangulation areas around the dome of Kilauea Volcano. This investigation is a part of the program of the United States-Japan Committee on Scientific Cooperation. A number of episodes of seismic activity took place during this time and were recorded simultaneously at various locations by instruments of the United States and Japanese groups.

As part of the cooperative program, an offshore area about 30 by 35 kilometers across, south of Kilauea caldera, was surveyed by 600 kilometers of echo-sounding traverses made by the Japanese training ship *Kagoshima Maru*, under the command of Captain S. Ueda. Position was controlled by a combination of radar from the ship and three transit stations on shore making simultaneous sightings every 10 minutes, timed by radio signal.

ISOTOPIC AND NUCLEAR STUDIES

The expanding program in geochronology strongly emphasizes the application of two or more methods of age determination to most geologic problems. Data obtained through a combination of isotopic methods are

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often useful in penetrating the barriers of metamorphic processes and permit insight into other history.

Extension of isotopic techniques developed first for geochronology opens new fields of investigation in which lead and strontium isotopes are used as tracers to obtain new information on the origin and source of volcanic and plutonic rocks. Some applications of the study of lead and strontium isotopes are given in the sections that follow on geochronology, isotopic studies of crustal evolution, and isotopic tracer studies.

GEOCHRONOLOGY

Basement rock age investigations

Rb-Sr age determinations by Z. E. Peterman and C. E. Hedge (1–64) of basement samples obtained from drill holes in the Williston basin of North Dakota and adjacent areas confirm subsurface extensions of the Churchill and Superior provinces of the Canadian Shield. The boundary between the Churchill (1.7 billion years) and the Superior (2.5 b.y.) provinces trends southward through western North Dakota.

Isotopic ages (Rb–Sr and K–Ar) of core and well cuttings from basement tests in the midcontinent region of North America, reported by W. R. Muehlberger and S. S. Goldich (1–63), show broad areas of relatively uniform ages. Subsurface extensions of the age provinces of the Canadian Shield, the Churchill and the Superior, are recognized in North Dakota and South Dakota.

In general the age of the basement rocks decreases to the south. Whole-rock Rb–Sr ages for granite and rhyolite from northeastern Oklahoma give consistent ages of 1,200 million years. Several cores from Kansas, to the northwest, are dated at 1,400 m.y., similar to published ages for some rocks from Missouri. Cores of rhyolite and of trachyte from the Wichita Mountains area of southwestern Oklahoma are dated at approximately 500 m.y.

The basement terrane of northwestern Texas and eastern New Mexico ranges in age from 1,300 to 1,400 m.y. and is overlain by a major volcanic sequence that is approximately 1,200 m.y. old. South of this area the crystalline basement rocks of Texas give ages of about 1,000 m.y., similar to ages of rocks in the Llano uplift of central Texas.

Central Texas

Geochronologic investigations of the rocks of the Llano uplift in central Texas have been continued by R. E. Zartman. Four whole-rock samples of the Valley Spring Gneiss give a Rb–Sr isochron age of 1,120 ± 25 million years and an initial Sr^{87}/Sr^{86} ratio of 0.706 ± 0.002. This age is significantly older than the age of 1,000–1,050 m.y. of the granites of the area.

Isochron plots for minerals of the individual gneiss samples yield an age of metamorphism of 1,000 ± 15 m.y., in good agreement with the time of major igneous activity. The strontium in the minerals of the older metamorphic rocks was isotopically homogenized at this time, with Sr^{87}/S^{86} ratios ranging from 0.716 to 0.775. From these data it is concluded that the plutons (Sr^{87}/Sr^{86}=0.706) could not have obtained their strontium from the surrounding metamorphic rocks unless some special mechanism operated to remove excess radiogenic strontium.

Black Hills, S. Dak.

A granite gneiss in the Black Hills, S. Dak., is approximately 2.5 billion years old as shown by preliminary Rb–Sr determinations of whole-rock samples by R. E. Zartman and an isotopic U–Pb age determination of zircon by T. W. Stern. The study of this ancient gneiss and related rocks is being continued by Zartman, Stern, and J. J. Norton. The gneiss provides a link between areas of lower Precambrian rocks in western Wyoming, eastern North Dakota and South Dakota, and western Minnesota. The new work in the Black Hills suggests that lower Precambrian rocks may have covered an extensive area in the north-central United States and that they were not necessarily restricted to several small nuclei.

Alkalic rocks of the midcontinent

R. E. Zartman and R. F. Marvin in cooperation with Allen Heyl and Maurice Brock have obtained K–Ar and Rb–Sr ages on biotites from a number of the mafic alkalic intrusions of the midcontinent region of the United States. These rocks are not all of the same age but appear to represent several different periods of emplacements. Dikes near Avon in southeast Missouri give an Early to Middle Devonian age; dikes, sills, and explosion breccia from the Rosiclaire fluorite district in Illinois and Kentucky yield an Early Permian age; and isolated dikes in western Pennsylvania, New York, and Vermont may be Jurassic or Early Cretaceous in age.

Of special interest in this investigation was the discovery of biotite phenocrysts in rocks from the Pennsylvania and New York localities which contain excess radiogenic argon and yield ages greater than can be inferred from stratigraphic relations. This suggests that the biotites may be xenocrysts derived from older basement rocks.

Minnesota River valley

Continuing the work started by E. J. Catanzaro [88] on the granitic gneiss at Morton, Minn., T. W. Stern (1–64) has analyzed 5 additional zircon concentrates and 1 allanite sample. The isotopic ages are discordant. The discordia curve age is 3,600 million years. The allanite ages form a reversed sequence ($Pb^{206}/U^{238} > Pb^{207}/U^{235} > Pb^{207}/Pb^{206}$). Three size fractions of the quartz diorite gneiss zircon at Granite Falls, Minn., have practically concordant ages, with a Pb^{207}/Pb^{206} age of 2,650 m.y. The zircon from the Sacred Heart Granite of Minnesota is also about 2,650 m.y., but not all samples of zircon from this granite are concordant.

Carbon–14 studies

Carbon-14 determinations have indirect applications in addition to their use in dating an event in time. A study by A. A. Rosen, U.S. Public Health Service, and Meyer Rubin, Geological Survey, (1–64) makes use of carbon-14 measurements to show that the contamination of the Kanawha River at Nitro, W. Va., is due almost entirely to chemical industrial wastes.

[88] E. J. Catanzaro, 1963, Zircon ages in southwestern Minnesota : Jour. Geophys. Research, v. 68, p. 2041–2048.

Because of the increase in the use of shells for carbon-14 age determinations, measurements were made of the natural carbon-14 activity of shells from living clams and snails collected from a variety of environments. Meyer Rubin and D. W. Taylor (1–63) conclude that shellfish living in lime-rich waters can metabolize shells having a built-in age of 3,000 years.

As a continuing study on changes of sea level, samples of organic material from borings for the Connecticut Turnpike Bridge over the Quinnipiac River in New Haven were taken from depths of 30 to 38 feet below mean sea level. J. E. Upson, E. B. Leopold, and Meyer Rubin (1–64) report that a sample from a thin bed of peat at about 31 feet, dated at 5,900± 2,000 years, represents a position of sea level not lower than 35 to 40 feet below present level. Computations based on this date suggest an average relative rise of sea level of between 1.7 and about 2 millimeters per year.

List of age determinations

A considerable part of the work of the Geological Survey geochronology laboratory is carried on in cooperation with Survey field geologists. Results of such service investigations throw light on local geologic problems and are reported under the appropriate headings in the section "Regional Geology". A list of these determinations for use in cross reference follows:

Samples dated	*State*	*Regional Reference*
Mica schist	New Jersey	Atlantic Coastal Plain.
Basement gneiss	do	Do.
Berkshire Schist	Massachusetts	New England and Eastern New York.
Ayer Granite	do	Do.
Canterbury Gneiss	Connecticut	Do.
Crystal-lithic tuff	North Carolina	Appalachian Region.
Glauconite, Hoadley Formation	Montana	Northern Rocky Mountains and Plains.
Boulder Creek batholith	Colorado	Southern Rocky Mountains and Plains.
Crystal-rich ash-flow tuff	do	Do.
Rhyolite tuffs	do	Do.
Snail shells	Wyoming	Do.
Quartz monzonite	Nevada	Basin and Range Region.
Welded tuff	Oregon	Columbia Plateau and Snake River Plain.
Glaucophane schist	California	Pacific Coast Region.
Intrusives, Sierra Nevada	do	Do.
Metavolcanics, Sierra Nevada	do	Do.
Wood, Baldwin Peninsula	Alaska	Alaska (west central).
Intrusives, Prince of Wales Island	do	Alaska (southeastern).
Intrusive, Talkeetna Mountains	do	Do.
Intrusive, Chickagof Island	do	Do.
Intrusive, Thiel Mountains	do	Antarctica.
Intrusive, Eights Coast	do	Do.

LIGHT STABLE ISOTOPES

Fluid inclusions

A detailed study of the chemical composition and relative deuterium concentration of primary fluid inclusions in ore and gangue minerals from the Cave-in-Rock, Ill., and the Upper Mississippi Valley districts was reported by W. E. Hall and Irving Friedman (1–63). The fluid inclusions in the early ore minerals are nearly saturated sodium-calcium chloride brines. Fluid inclusions in late minerals are less concentrated and have a lower deuterium concentration.

In the Cave-in-Rock fluorite district the composition of primary fluid inclusions in yellow fluorite, the earliest ore mineral, is similar to that of connate water in the Illinois basin in the same strata as the ore deposits. The change in composition of fluid inclusions in the later quartz and sulfide minerals indicates that water of different origin, possibly magmatic, was introduced. Connate and possible magmatic waters were largely flushed out during deposition of the gangue minerals in the last stages of mineralization, and the composition of the fluid inclusions in these gangue minerals trends toward that of meteoritic water.

In the Wisconsin-Illinois-Iowa district, the fluid inclusions in the ore minerals are highly concentrated sodium-calcium chloride brines that have a high relative deuterium concentration; whereas the inclusion fluid in late gangue minerals contains less deuterium and is relatively dilute.

Irving Friedman, Thorbjörn Sigurgeirsson, and Örn Garbarsson (3–63) determined the deuterium content of 159 samples of waters of all types in Iceland. On the basis of the deuterium analyses, the water from boreholes near Reykjavik does not appear to originate from local precipitation. The variations suggest that deuterium values can be used to determine the time of travel of recharge water as well as the surface recharge area.

A review paper by Irving Friedman, A. C. Redfield, Beatrice Schoen, and Joseph Harris (3–64) summarizes more than 1,000 analyses of the distribution of deuterium in waters of the North American continent and the surface waters of oceans contiguous to the continent. The various possible causes for deuterium fractionation are considered, and the regional characteristics of the surface waters of North America are described and interpreted as reflecting the history of the water in the course of the hydrologic cycle.

NATURAL RADIOACTIVE DISEQUILIBRIUM STUDIES

Natural fractionation of uranium isotopes

The mechanism of uranium-isotope fractionation in uranium ore deposits was studied by J. N. Rosholt (p. B84–B87), of the Geological Survey, and E. L. Garner and W. R. Shields, of the National Bureau of Standards. It is suggested that the U^{234} in a given sample may be contributed in two ways. Atoms generated in place from the radioactive disintegration of U^{238} (authigenic U^{234}) are subject to differential migration with respect to U^{238}. Those atoms that have been transported and mixed with U^{238} and U^{235} (allogenic U^{234}) will remain with these two isotopes and are not subject to further preferential leaching.

Pattern of uranium fractionation in soils

The isotopic composition of uranium has been determined by mass-spectrometric measurements in four soil profiles: (1) a brunizem soil derived from glacial till in Mower County, Minn., (2) a gray-brown podzolic soil derived from loess in Fillmore County, Minn., (3) a brown podzolic soil derived from Cretaceous shale in the La Sal Mountains, Utah, and (4) a brown soil derived from trachyte and volcanic tuff in the Buell Mountain area, Apache County, Ariz. Soil profiles include continuous sampling of the A, B, and C horizons. The uranium content ranges from 2 to 3.5 parts per million in the glacial soils to 6 ppm in the shale soil.

A very regular pattern exists for the variation of the U^{235}/U^{234} ratios with depth. In each profile the ratio increases with depth, and the U^{234} is most deficient in the C horizon. The C horizon in the Arizona profile has the greatest variation where U^{234} is 42 percent deficient with respect to the amount required for radioactive equilibrium with the parent U^{238}. These results indicate that U^{234} is preferentially leached to the greatest degree in the least weathered material in the profile Soluble uranium with U^{234} in excess of equilbrium requirements migrates upward in the profile and continually exchanges with uranium contained in the A and B horizons to produce an isotopic composition in the upper horizons which is less deficient in U^{234}.

This interpretation is in agreement with the suggested mechanism of uranium-isotope fractionation. The C horizons in soil profiles contain the greatest proportion of authigenic U^{234} , whereas the proportion of allogenic U^{234} increases upward in the soil profile.

ISOTOPIC TRACER STUDIES

Hydrothermal brines near Niland, Calif.

Studies of the isotopic composition of lead in the hydrothermal brine and in rocks in the vicinity of Niland, Calif., have been continued in a cooperative study by B. R. Doe, C. E. Hedge, and D. E. White (1–63). The lead isotopic composition varies little in analyzed samples, which have a range in Pb^{206}/Pb^{207} ratios of 1.215 to 1.222, and the composition is distinctly different from that of two samples of obsidian from the area, which have ratios of 1.207 and 1.210. The lead isotopic composition of the brine is unlike that of lead in ocean water, judging from the available analyses of lead isotopes in pelagic sediments and manganese nodules from the Pacific Ocean. The brine lead, however, resembles that of sediments of the region and of the Gulf of Mexico ($Pb^{206}/Pb^{207} \approx 1.208$–$1.222$).

The value of Sr^{87}/Sr^{86} in samples of the brine is uniform at about 0.711, which is also distinctly different from that of a sample of obsidian from the area ($Sr^{87}/Sr^{86} = 0.705$) and of ocean water (approximately 0.708). Samples of the sediments from the area have values for Sr^{87}/Sr^{86} in the range of 0.713 to 0.718, distinctly greater than that of brine. Strontium leached from a sample of sediments, however, had a ratio $Sr^{87}/Sr^{86} = 0.710$, and a similar value was found for Salton Sea water. These observations suggest that the host sediments of the area may have been the source of the strontium of the brine and of the Salton Sea water. (See also sections "Field Studies in Petrology and Geochemistry" and "Light Metals and Industrial Minerals.")

Isotopic composition of ore lead from Nevada

A. P. Pierce and M. H. Delevaux have investigated the isotopic composition of galena from a series of ore deposits and prospects in Nevada. The samples were taken along a 40-mile sector of the trend of intrusive stocks that cut across the Paleozoic thrust belt of central Nevada. The samples of ore lead are of similar isotopic composition, with a range in Pb^{206}/Pb^{207} of 1.211 to 1.239, and are somewhat enriched in radiogenic lead. Samples from the upper plate of the Roberts thrust do not differ measurably from those from the lower plate. The results obtained to date support the idea, favored by geologists working in this area, of a northwest-trending mineral belt of cogenetic ore deposits.

Ore lead in the Colorado Rockies

Lead-isotope analyses of 70 galena samples from the Colorado Rockies have been completed by M. H. Delevaux in a study of ore lead with J. C. Antweiler, A. P. Pierce, R. S. Cannon, Jr., and K. L. Buck. Within the Colorado mineral belt, where there is strong geologic evidence of major mineralization cogenetic with Laramide igneous activity, a well-defined family of ore lead generally deficient in uranium-derived lead (B-type of anomaly) is found. Galena from deposits outside the mineral belt shows considerable variety, and tentatively three types are recognized which suggest three different episodes of mineralization from Precambrian to Tertiary.

Low-temperature deposits in Paleozoic rocks on the fringe of the Leadville, Colo., district, which are similar in many ways to the lead-zinc deposits of the Mississippi Valley, show anomalous excesses of uranium- and thorium-derived leads and hence are J-type leads similar in isotopic composition to the anomalous J-type lead of the Mississippi Valley.

Tri-state zoned galena crystal

Significant differences in isotopic composition of lead in successive growth zones of a large crystal of galena from Picher, Okla., were found by R. S. Cannon, A. P. Pierce, Jr., and M. H. Delevaux (1–63). A range in the ratio of Pb^{206}/Pb^{204} from 21.97 to 22.92 was found. The variations within the single crystal are roughly one-fifth of the overall variation of Mississippi Valley J-lead.

Reference lead sample

In connection with analyses of lead for isotopic abundance ratios a reference sample is included at regular intervals as a means of monitoring the performance of the mass spectrometer. Data on lead reference sample GS–4 are given by M. H. Delevaux (1–63).

Copper isotopes

The variations of Cu^{63}/Cu^{65} in approximately 100 natural samples were investigated by S. S. Goldich in collaboration with W. R. Shields, E. L. Garner, and T. J. Murphy of the National Bureau of Standards (Shields and others, 1–63). No variations larger than the analytical error were found for chalcopyrite and for two meteorites. Two samples, one of bornite and one of chalcocite, showed about 0.5 per mil enrichment in Cu^{63}. A number of secondary copper minerals show enrichment in Cu^{65}. The maximum variation was found for a sample of aurichalcite with an enrichment of approximately 1 percent in Cu^{65}.

ISOTOPIC STUDIES OF CRUSTAL EVOLUTION

Isotopic variation of lead in granitic rocks

Isotopic analyses by B. R. Doe (1–64) of lead from granitic rocks and potassium feldspars from granites in several selected parts of the United States suggest that the oldest Precambrian rocks contain lead with isotopic rock compositions that fit fairly well the models of derivation of the lead from an "infinite reservoir." Such lead commonly is called normal lead. The lead of younger rocks generally departs from the "infinite reservoir" model in a manner suggesting regional or provincial differences.

In the Eastern United States the lead in granitic rocks approximately 1,000 million years old and younger tends to be more radiogenic than expected, giving rise to a negative anomaly. The negative anomaly for Pb^{206}/Pb^{207} is generally greater than for Pb^{208}/Pb^{204}. Lead of Tertiary obsidian in the Pacific coast region also shows negative anomalies, but the anomalies are about equal for Pb^{206}/Pb^{207} and for Pb^{208}/Pb^{207}.

In the Rocky Mountain region, however, Pb^{206}/Pb^{207} in Cretaceous and Tertiary granitic rocks tends to be less radiogenic than expected, producing a positive anomaly; whereas Pb^{208}/Pb^{204}, in general, appears to fit the model and is about as radiogenic as expected. The Precambrian granitic rocks tend to have the more common negative anomaly. The lead-isotope ratios tend to be more erratic in Cretaceous and Tertiary granitic complexes intruded into Precambrian terranes. This erratic behavior is extreme in the Rocky Mountain region, particularly among units of the Boulder batholith.

The granitic rocks of the Eastern United States appear to contain normal lead. The isotopic composition of lead in separates of microcline from igneous and metamorphic rocks of the Llano Uplift has been determined by R. E. Zartman (1–64). All the microcline from the igneous rocks has a similar lead isotopic composition (Pb^{206}/Pb^{204}=16.6–17.0; Pb^{207}/Pb^{204}=15.4–15.5; Pb^{208}/Pb^{204}=36.4–36.7) which yields model ages close to the determined Rb–Sr age of 1,000–1,100 m.y. In contrast with the granitic rocks, the microcline samples from the Valley Spring Gneiss show a wide range in isotopic composition (Pb^{206}/Pb^{204}=17.1–19.4; Pb^{207}/Pb^{204}=15.5–15.8; Pb^{208}/Pb^{204}=36.8–38.2), which is suggestive of a more complex history.

It is probable that the plutonic igneous rocks obtained most of their lead from a rather uniform source, possibly deep crustal or upper mantle layers which may also be the reservoir of so-called "conformable" ore lead or normal leads. The presently exposed metamorphic host rocks could have contributed a significant portion of the lead to the igneous rocks only through the operation of some special mobilization and mixing mechanism.

The Pb^{206}/Pb^{204} ratios in whole-rock samples of two igneous rocks were determined and calculated as a function of time, by use of the presently observed U/Pb ratio in the rocks. The ratios became equal to those of the microcline in the samples at approximately 1,100 m.y. ago, suggesting an initial lead homogeneity and subsequent closed-system conditions. The microcline and the total rock from four metamorphic rocks, however, were calculated to have equal lead isotopic compositions at times other than the time reasonably attributable to some tectonic event. Uranium and lead migration and initial lead inhomogeneity in these rocks are considered as possible causes of this discrepancy.

Isotopic variation of lead and strontium in volcanic rocks

The isotopic composition of lead in basaltic rocks of Japan, Iwo Jima, and the Hawaiian Islands has been determined by M. Tatsumoto (2–64). The volcanic rocks of Japan contain lead in near agreement with models of derivation from an "infinite reservoir" but tend to have small negative anomalies, whereas the sample from Iwo Jima has a much larger negative anomaly. Hawaiian Island volcanic rocks contain lead less radiogenic than expected from the "infinite reservoir" model (positive anomaly), and in addition have smaller values of Pb^{207}/Pb^{204} than the rocks from Japan and Iwo Jima. This is indicative of a derivation of the Hawaiian volcanic rocks from a different source which has had a distinctly lower value of U/Pb for billions of years. Thus significant differences in lead isotopic composition exist in the sources of oceanic basalt, and are not solely found in rocks of undoubted continental origin.

G. R. Tilton, P. W. Gast, and C. E. Hedge (1–64) have investigated Pb and Sr isotopic variations in volcanic rocks from Ascension and Gough Islands on the mid-Atlantic ridge, and in the Columbia River and Snake River flows of the Northwestern United States. Neither the oceanic nor the continental rocks have lead or strontium of uniform isotopic composition. The Pb^{206}/Pb^{204} ratios range from 18.35 to 19.55;

the Pb^{208}/Pb^{204} ratios range from 38.9 to 39.2. The Pb^{208}/Pb^{204} ratios, much restricted in their range compared to the Pb^{206}/Pb^{204} ratios, in all the basalts agree well with those from young conformable galena deposits; however, only the Columbia River Basalt has Pb^{206}/Pb^{204} ratios similar to the galena samples. The lead from the Gough Island and from the Snake River flows is apparently deficient in Pb^{206}, whereas the Ascension Island rocks appear to be enriched in radiogenic Pb^{206}. Although Pb^{206} is more radiogenic at Ascension than at Gough, the Sr^{87} is less radiogenic at Ascension. On the basis of data presently available, it appears that the Columbia River Basalt has higher Pb^{206}/Pb^{240} ratios and lower Sr^{87}/Sr^{86} ratios than the basalt of the Snake River Group.

Analyses by C. E. Hedge (1–64) of strontium-isotope abundances in approximately 100 volcanic rocks reveal significant variations in the ratios of Sr^{87}/Sr^{86} at the time of eruption. The range of 0.7025 to 0.7065 for Sr^{87}/Sr^{86} for oceanic samples is small, but nevertheless it is analytically significant and suggests that the upper mantle beneath the oceans is not entirely homogeneous with respect to the Rb/Sr ratio.

Continental volcanic rocks show a wider range in their initial Sr^{87}/Sr^{86} ratio, 0.7025 to 0.7110, than do oceanic volcanic rocks. Incorporation of relatively radiogenic crustal materials may be a cause of the wider range in initial Sr^{87}/Sr^{86} of continental compared to oceanic volcanic rocks; however, contamination does not appear wholly adequate as a single process to explain all the data. In several rocks series which might be attributed to magmatic differentiation, variations in initial Sr^{87}/Sr^{86} with rock type were observed. The variations in Sr^{87}/Sr^{86} suggest that the members of the rock series could not be derived from a single parent magma through magmatic differentiation within short periods of time.

HYDRAULIC AND HYDROLOGIC STUDIES

SURFACE WATER

Hydraulic studies of surface water have helped show how differences in bed material, temperature, and shape of channel affect the flow of water in laboratory flumes and natural channels. Hydrologic studies have helped show how the amount of flow is affected by natural or manmade features upstream and how the areal and time distribution of streamflow can be related to topographic or hydrologic parameters.

Stream-channel underflow

C. W. Sullivan found that the 40 cubic feet per second of streamflow that disappears in the gravel streambed upstream from the stream-gaging station on Spavinaw Creek in northeastern Oklahoma reappears 2½ miles downstream. The fact that it took only 21 hours for fluorescein dye to travel this distance indicates that the underground flow is largely through solution channels.

Diurnal fluctuation produced by hydraulic changes

F. F. LeFever reports that in midautumn and midspring the flow of the upper reaches of the Middle Loup River in Nebraska varies about 200 cubic feet per second during the day, which is a variation of about 25 percent. He tentatively attributes this variation in flow to storage and release of water in response to changes in bed regime resulting from changes in the ability of water to transport sediment as the viscosity changes with a change in water temperature through a critical range.

Flow through contractions

K. V. Wilson has found that discharge computed by the U.S. Geological Survey procedures for contracted sections downstream from wide flood plains agrees well with discharge measured by current meter where the flood plains are relatively clear of trees and brush. At sites with heavily wooded flood plains, however, the computed discharge tends to be higher than the measured discharge. These comparisons were made at 60 sites to test the applicability of methods based largely on laboratory experiments.

Longitudinal dispersion of a solute

By numerical solutions of a dispersion equation, Nobuhiro Yotsukura, G. F. Smoot, and D. I. Cahal show that the longitudinal-distribution coefficient of a solute is almost a linear function of the Reynolds number. By analysis of experimental data, however, they show that in steady rectangular flow the coefficient is proportional to the nine-tenths power of the Reynolds number. Tracer studies in natural streams show greater dispersion than given by an extrapolation of the experimental relation to Reynolds number.

Shape of vertical-velocity profiles

N. C. Matalas and W. J. Conover have found that the statistical model of turbulence for two-dimensional flow in open channels based on random transfer of momentum gives vertical-velocity profiles that are defined by a three-parameter hyperbolic cosine function in which two parameters reflect the effect of bed roughness and fluid viscosity and the third is the mean velocity in the vertical. To test the applicability of the theoretical results, they fitted curves to vertical-velocity data for water in natural channels and in a laboratory flume and for air in a wind tunnel and found that the hyperbolic cosine function provides a somewhat better fit to the observed data than does a logarithmic function.

Relation of bed material and open-channel flow

By collecting and studying information on bed-material size at 60 stream sites where the value of Manning's n had previously been determined, Jacob Davidian, E. V. Giusti, and R. H. Walker found that for streambeds formed of gravel or coarser material the value of n is related to the relative roughness times the square of the bed-material sorting coefficient. They also found that the Wolman areal pebble-count method of determining bed-material grain-size distribution gives results compatible with those obtained by wet sieving, in that for grain sizes where both methods are feasible the results agree.

Flow in open channels

H. J. Tracy, C. M. Lester, and W. W. Emmett found from studies in a laboratory flume that the resistance a smooth channel offers to the flow depends as much on the waviness of the channel walls as it does on the texture of the walls. They also found that near the sidewalls the vertical-velocity profiles are not logarithmic in shape as they are farther away from the walls.

By measuring six components of turbulent stress in airflow in a rectangular closed conduit and by measuring the secondary motion in the corner region, H. J. Tracy obtained data from which he shows that the secondary motion can be explained by the lateral and vertical components of the turbulence through use of Navier-Stokes equations.

D. G. Anderson finds that the best mean conveyance to use in computing channel-roughness losses varies with the type of channel. In some types of channel the geometric mean of the conveyance at the ends of the reaches gives the best results, but in other types of channel the arithmetic, harmonic, or quadratic means give better results. To minimize the effect of the uncertainty as to which mean to use, enough sections should be chosen so that the conveyance at one end of the reach does not differ from that at the other by more than 40 percent.

Flow in alluvial channels

According to D. B. Simons and E. V. Richardson, the velocity of flow in straight alluvial channels with sand beds can be determined from the Chezy equation if the measured depth is corrected to account for separation zones downstream from roughness elements such as dunes. The depth correction is related to depth and slope for each form of bed roughness for a limited range of size of bed material. The value of the Chezy coefficient is related to the ratio of the depth correction and the depth, and to the shear-velocity Reynolds number.

Oscillations in the water surface of reservoirs

G. L. Haynes, Jr. (p. B158–B162) shows that data from a single weather station provide only a general indication of the effect of wind and barometric pressure on the oscillations in water surface of Elephant Butte Reservoir in New Mexico. Analysis of the causes and characteristics of setups and seiches does, however, aid in selecting the optimum location for reservoir gages and in interpreting the records of stage.

Relation of annual runoff to meteorological factors

According to M. W. Busby (p. C188–C189) annual runoff is significantly related to seven meteorological factors. Using annual runoff for 68 widely scattered stream-gaging stations and records from first-order weather stations, he obtained a relation by multiple regression that has a standard error of estimate of 30 percent.

Comparison of departures in annual runoff

In order to compare the severity of streamflow deficiencies during the 1942–56 drought in the southwest, J. S. Gatewood and others (1–64) developed a procedure for reducing annual runoff for all gaging stations to a comparable basis regardless of differences in variability. With this procedure, which involves expressing the annual departure in terms of an index of variability, the departures from normal for a station with a wide range in annual discharge are more easily compared with those for a station with a narrow range than when the departures are expressed in the customary way.

Relations of monthly discharge and precipitation

H. C. Riggs (P. C185–C187) shows that for two pairs of stream-gaging stations in Tennessee, better estimates of monthly discharge can be obtained by including monthly precipitation in the regression analysis of monthly discharge than by using discharge alone. The basins for one pair of stations are adjacent and for the other are 100 miles apart.

Improved regression estimates

N. C. Matalas has found that the mean and variance of a short-term sequence of hydrologic events can be improved by relating the events to concurrent events in a long-term sequence if the coefficient of correlation exceeds 0.5 and if "noise" is added to each estimated event. The noise is a random variate with zero mean and with variance equal to the variance of the observations for the short sequence about the line of regression. If noise is not added, a coefficient of correlation of at least 0.8 would be required to give improved estimates.

Variation in seepage from Crater Lake

Hydrologic evaluation of monthly and yearly fluctuations in the level of Crater Lake, Oreg., by K. N. Phillips shows that the average loss by evaporation is 23 inches a year, and that the seepage ranges from 87 cubic feet per second to 107 cfs depending on the level of the lake. The fact that the seepage increases as the level of the lake rises acts as a governor on the level of the lake and explains why the fluctuation in lake level during the past 70 years has been only about 16 feet despite rather extended sequences of wet or of dry years. Annual precipitation on the lake is deduced to be about 7 percent greater than that observed at the Crater Lake Post Office.

Lake-volume formula for Indiana

The surface area (A) and the maximum depth (D_M) of lakes are more often available than is the volume (V) of water in the lake. M. D. Hale found that the relation $A=1.82\left(\frac{V}{D_M}\right)^{1.1}$ based on surveys of 85 natural lakes in Indiana could be used to estimate the volume of 39 other Indiana lakes with a maximum error of 40 percent. In the formula, A is expressed in acres, V in acre-feet, and D_M in feet. For two-thirds of the 39 lakes the estimated volume was within 10 percent of the value based on lake surveys.

Low-flow relations in Delaware River basin

For streams in the Delaware River basin, A. G. Hely and F. H. Olmsted (2–63) found that in part of the basin low flows could be related to geology by analyzing the ratios of discharge exceeded 90 percent of the time to mean discharge and by assigning a ratio to each of 10 geologic classifications. For two-thirds of the 19 basins studied, basin ratios weighted according to geology check the observed ratios within 13 percent. For the same area, C. H. Hardison and R. O. R. Martin (2–63) found that storage-draft relations can be estimated from the median annual 7-day low-flow and size of drainage area. They suggest a method for estimating the median annual low flow for an ungaged stream that requires discharge measurements at times when the flow is not affected by surface runoff from current rainfall.

Relation of characteristic flows and drainage area

H. C. Riggs (p. B165–B168) used gaging-station records and other flow information in the Rappahannock River basin in Virginia to establish relations between discharge and drainage area for various concurrent events. The results may be used to estimate flows of comparable frequency on the smaller streams in the basin.

Low-flow relations in Ohio

In a study of annual low flows for durations of 1 day to 12 months, W. P. Cross (1–63) has related the pattern of duration, frequency, and annual minimum rates of flow to the mean annual discharge and to the median 7-day annual minimum as an index.

Storage-draft relations by probability routing

C. H. Hardison (1–64) defines relations between storage, draft, and variability of annual discharge for streams in which the annual discharges have a log-normal distribution. The variability is defined by the standard deviation of the logarithms of the annual discharge, and the storage requirements are based on solutions of probability-routing equations by an electronic computer.

Effect of reservoirs on water yield

In arid and semiarid climates, part of the flood waters retained by flood-retarding reservoirs is lost to evaporation, thus decreasing the total amount of flow downstream. For the Sandstone Creek watershed upstream from Cheyenne, Okla., F. W. Kennon found that reservoirs controlling 75 percent of the 85.4 square miles of drainage area decreased the flow during 2 years of above-normal precipitation (1959 and 1960) by 20 percent.

Effect of swamps on streamflow

E. G. Miller reports that during the summer months the flow out of Great Swamp in New Jersey is sometimes considerably less than the inflow. The decrease on one day in July was measured as 4.2 cubic feet per second or nearly three-quarters of the inflow to this swamp of about 10 square miles.

Effects of upstream use on channel width

R. W. Lichty attributes the decrease in channel width of the North Platte River in western Nebraska to the decrease in flow that has resulted from change in upstream water use during the past 60 years. The mean flow has decreased to one-third and the mean annual peak flow to one-quarter of their former values. The channel width has decreased from about 2,800 feet to about 500 feet.

Optimum stream discharge for salmon spawning

S. E. Rantz (2–64) found that for streams in the northern California Coast Ranges the discharge most preferred by king salmon for spawning is related to the mean discharge of the stream and to the ratio of stream width to drainage-area size.

Effect on change in density of rain gages

S. P. Sauer found that areal storm rainfall computed from 10 rain gages on the 70-square-mile Mukewater Creek study area in west-central Texas agreed very well with that computed from 19 gages in the same area. For two-thirds of the 121 storms studied, the difference was within 3 percent, which is small in comparison with the standard error of estimate of the rainfall-runoff relation for which the rainfall data were used.

GROUND WATER

Ground-water research in the Geological Survey was accelerated substantially during the year in response to the growing need for basic information on principles of occurrence, movement, and chemistry of water beneath the land surface. Such information is needed to handle national water problems. Research in borehole geophysics was undertaken to develop techniques of extracting more and better information from costly test holes. Water flow in clay, the principal factor controlling gross movement of water in complex sedimentary systems, was subjected to intensive analysis to explain deviations from so-called Darcy's-law flow. Work was begun on hydrologic applications of various "remote-sensing" methods including infrared and radar imagery as related, for example, to mapping of aquifers and reconnaissance of areas of ground-water recharge and discharge. Emphasis on geochemical principles was increased, in view of their application to problems of ground-water replenishment, flow, and discharge, and of generation, movement, and disposal of contaminants in the subsurface. Emphasis was also increased on laboratory study of both saturated and unsaturated flow, and on both laboratory and field methods of measuring specific yield and the storage coefficient. Major research projects were undertaken (a) on the fundamental controls of sediment deposition and, hence, on permeability distribution in the Atlantic Coastal Plain hydrologic system; and (b) on the occurrence and discharge of brine in the Permian basin, which spoils large quantities of otherwise usable water.

Permeability distribution in sedimentary basins

Studies by R. R. Bennett and J. D. Bredehoeft (chapter D) of core analyses and sonic and neutron logs indicate that the permeability of the Tensleep Sandstone in the Bighorn Basin, Wyo., decreases rapidly from the margins to the center of the basin. Permeability was estimated from an empirical correlation with porosity, a correlation developed from the core analyses and bore-hole logs.

Vertical permeability, transmissibility, and storage coefficients from water-level data

Work by E. P. Weeks (chapter D) at Madison, Wis., has resulted in methods for analyzing aquifer-test data by finite-difference techniques and by means of a type curve to produce quantitative information on vertical permeability, and on the ratio of horizontal to vertical permeability, in the vicinity of a partially penetrating well. Weeks (p. B181–B184) has also developed a technique for analyzing the recession curve of water level in an observation well after a period of recharge in terms of the transmissibility and storage coefficients of the glacial outwash penetrated by the well.

Analysis of drillers' descriptions in terms of permeability values

Results of 9 aquifer (pumping) tests and 500 specific-capacity tests made on wells penetrating arkosic deposits of the Kern River alluvial fan in the San Joaquin Valley, Calif., were used by R. H. Dale in developing techniques for relating drillers' descriptions of texture to definite ranges of permeability values. The term "gravel" was found to indicate permeabilities of 1,000 to 10,000 meinzer units (gallons per day per square foot); "coarse to medium sand," 100 to 1,000; "fine sand to silt," 0.01 to 100; "clay," 0.001 or less; and "gravel to clay," 10 to 100.

Reanalysis of California aquifer tests

Earlier data on aquifer tests in California were selectively reexamined by E. J. McClelland, using the method of Hantush.[89] The reanalysis gave more con-

[89] M. S. Hantush, 1960, Modification of the theory of leaky aquifers: Jour. Geophys. Research, v. 65, no. 11, p. 3713–3725.

sistent results and significantly lower values of transmissibility than those obtained by use of the unmodified Theis equation.

Research on permeability and specific yield

Several studies of permeability and specific yield of porous media are underway at the hydrologic laboratory in Denver, under the direction of A. I. Johnson. Studies by Johnson and Benjamin Reyes of the effect on laboratory permeability determinations of variables such as entrapped air, particle size, porosity, and hydraulic gradient have shown, among other things, good correlation between permeability and particle size if both particle-size distribution and dominant particle size are treated statistically. Quantitative data on the decrease of permeability that occurs in the zone of aeration with a reduction in moisture content have been obtained in a study just completed by Johnson and R. C. Prill. Johnson, Prill, and D. A. Morris showed that the effect of temperature on centrifuge moisture equivalent (which can be correlated with specific yield) was sufficient to require establishment of a standard temperature for centrifuging; also, that relative humidity must be maintained near 100 percent. In the same report, the authors showed the length of time required for "complete" drainage of columns of various materials to establish specific yield and specific retention. Johnson, W. K. Kulp, and W. E. Teasdale, using a nuclear soil-moisture meter in three areas of changing ground-water levels in California, showed that specific yield depends not only on the texture but on the thickness of the material, the time of drainage, and the texture of overlying and underlying materials.

Departures from Darcy's law in water movement in clay

Laboratory work by H. W. Olsen has established that so-called non-Newtonian liquid movement (departures from Darcy's law of flow in exact proportion to hydraulic gradient) in fine-grained material, reported in the literature as due to clay-water interaction, can be explained in part by the effects of atmospheric contamination on air-water menisci and air bubbles in capillary tubes. It is thought that textural, or fabric, changes are responsible, in a way not yet explained, for remaining deviations from Darcy's law.

Analog models show rate at which aquifers can be flushed of contained fluids

J. M. Cahill, in the hydrologic laboratory at Phoenix, used hydraulic sand models as analog "computers" to determine the rate at which the native fluid in an aquifer system could be displaced by another fluid entering as recharge from the land surface. The several models simulated aquifers in which the horizontal permeability exceeded the vertical permeability by specified ratios. The recharge fluid was "tagged" with radioactive phosphorus (P^{32}), and the effluent was monitored for the changing concentration of this radioisotope. The data were plotted to show the proportion of native aquifer fluid appearing in the effluent versus the volume of fluid recharged. Within the range of permeability ratios that was selected, the results can readily be converted into the rates at which similar aquifers can be flushed of their contained fluid.

Indirect recharge of Dakota Sandstone in South Dakota

F. A. Swenson, in a study of the hydrology and geochemistry of limestone and other soluble rocks, has obtained significant information on recharge to the important artesian aquifer in South Dakota known by the general name Dakota Sandstone. Water enters the Mississippian Pahasapa Limestone on the flanks of the Black Hills and moves eastward in that formation and its subsurface equivalents, well below the Dakota Sandstone. East of the middle of South Dakota, where the intervening strata were eroded away in pre-Dakota time, the limestone lies directly below the Dakota and recharges it. West of the zone of recharge, water in the Dakota is virtually stagnant and has a high dissolved solids content, principally sodium chloride. In the zone of recharge the water is of the calcium sulfate type and is less mineralized. To the east, the water "splits" around the Sioux Quartzite ridge; the water is of the sodium sulfate type to the north where circulation is poor, and of the calcium sulfate type to the south where circulation is better.

Well tests in permeable limestone terrane

As part of the construction of a hydrologic model of the Roswell, N. Mex., ground-water basin, J. L. Kunkler supervised "packer isolation" tests on four water wells. The tests indicate that certain zones of the San Andres Limestone and the Grayburg Formation have very high transmissibility locally, and transmit effects of discharge from nearby flowing wells very rapidly. Substantial but as yet unexplained differences in artesian pressure between zones were noted in one well.

Structural control of water in crystalline rocks

Studies at the Georgia Nuclear Laboratory in Dawson County, Ga., of the movement of water through the Precambrian Ashland Mica Schist in relation to movement and adsorption of radioactive contaminants (J. W. Stewart, 1–64) have yielded useful information on the occurrence of water in crystalline rocks. C. W. Sever (chapter D) has shown that the courses of streams that drain the Ashland terrane are governed primarily by joints, but the direction of ground-water flow toward the stream is controlled instead by the strike of bedding, schistosity, and axial-plane cleavage.

Effect of earthquakes on ground-water levels

L. D. Carswell noted earthquake-caused fluctuations of water levels in three observation wells in the Martinsburg Shale in Dauphin County, Pa. These and wells in 4 other counties showed fluctuations resulting from 7 separate earthquakes in August–November 1963, when ground-water levels were at seasonal lows; earthquakes of similar magnitude did not produce fluctuations at other times of the year. The fluctuations appear to be greatest in wells within the cone of depression of pumping of nearby wells. All the wells are in areas where the ground water has an upward component of flow. The fluctuations seem to have no relation to depth of well or to aquifer characteristics as revealed by pumping tests.

The March 27, 1964, earthquake in Alaska (see section "Alaskan Earthquake") was unusual in that it produced water-level fluctuations in wells in the upland areas of the Martinsburg Shale, where ground water has a large downward component of flow, in addition to wells in lowland areas where the ground water has a large upward component of flow. In the areas of downward ground-water flow the amplitude of the water-level fluctuation was approximately proportional to the depth that the wells penetrated the aquifer. The deepest well (400 ft) had the largest fluctuation (0.8 ft) and a net lowering of water level of 0.35 foot after the passage of the earthquake. In a nearby well in a valley, where the ground water has an upward component of flow, the total water-level fluctuation exceeded 1 foot but could not be determined more precisely because of overlap in the recording instrument. There was a net rise of water level in the well of more than 0.8 foot after the passage of the earthquake.

Water levels in wells respond to sonic booms

Water levels in two wells in the Spokane, Wash., area have been affected by sonic booms, according to D. R. Cline. The level in one well, 11 miles north of Spokane, fluctuated 0.06 foot, 0.05 foot below and 0.01 foot above the normal water level, coincident with a sonic boom just north of Spokane. In another well 13 miles east of Spokane, the level fluctuated 0.09 foot, 0.08 foot below and 0.01 foot above the normal water level due to a sonic boom in that area.

Temperature fluctuations in shallow ground water

Daily temperature measurements were made by R. C. Heath at 5 depths from land surface to 18 feet at Albany, N.Y., over a period of 18 months. His results (3–64) show that temperature waves originating at land surface due to changes of air temperature are nearly dampened out within the soil zone and upper few feet of the zone of saturation. The range in monthly average temperature of the soil at a depth of 1.5 feet was 43°F, compared to 3.6°F in ground water at 17.7 feet.

Creation of artesian conditions by soil freezing

In a pumping test made during cold weather at Great Smoky Mountains National Park, Tenn., J. H. Criner and R. H. Bingham noted apparent artesian conditions in what was thought to be a water-table area. A second test in warm weather indicated water-table conditions. Temporary artesian conditions due to freezing of soil have been noted previously in more northerly States, but this is the first such situation noted in Tennessee, and one of the first to provide quantitative data on the effect.

Correlation of water-level records

Statistical methods of linear regression, long used to correlate streamflows in nearby basins so as to enable estimation of flow during periods of missing record in one of the basins, have been applied by H. G. Healy (chapter D) to water-level fluctuations in observation wells in Madison and Duval Counties, Fla. It was found possible to correlate records in wells as much as 17 miles apart. In addition to estimates of fluctuations during periods of missing record, the method enables identifying wells that show representative areal trends of fluctuation and those that do not.

Technique for anticipating well clogging

In a study at the Bryce State Hospital, Tuscaloosa County, Ala., K. D. Wahl discovered that precipitation of iron compounds, in part as a result of activities of "iron bacteria," was responsible for decreases in yield of the well supplying most of the water. The construction of the well and water system was such that the plugging was not discovered until the well was almost useless and extensive acidification operations were necessary to restore yield. Now a recorder on a nearby well is used to detect incipient plugging; when the drawdown in the recorder well caused by pumping the supply well decreases, plugging is known to have begun and the yield of the supply well is restored by a relatively minor procedure.

Correlation of spring discharge and precipitation

A time-series analysis by A. O. Westfall (2–63) of the discharge of Byrds Mill Spring near Fittstown, Okla., shows that fluctuations in discharge can be accurately correlated with fluctuations in precipitation at Ada, Okla., some 10 miles away. The seasonal peaks and troughs in precipitation are reflected at the spring 7 to 8 months later.

GROUND-WATER–SURFACE-WATER RELATIONS

Because the principles governing the movement and occurrence of surface water and ground water differ in many respects, the methods by which they are investigated likewise differ. For this reason they are commonly studied separately. In many areas, however, water in streams and lakes and water underground are closely related and interdependent. Included in the Survey's hydrologic investigations, therefore, are studies of (a) the magnitude and source of ground-water contributions to streamflow, (b) methods of forecasting the low flow of streams by use of ground-water levels and aquifer characteristics, (c) the effects of changes in the stage of streams and surface impoundments on ground-water levels and (d) other subjects concerning the relations of water in the two environments.

Low flow of streams related to ground-water storage by use of basin constants

Research on ground-water storage and its relation to low flow of streams by M. I. Rorabaugh and W. D. Simons led to derivation of basin constants by recession analyses for streams in western Montana. The basin constant, a combination (a) of distance to divide, (b) of storage coefficient, and (c) of transmissibility, is descriptive of the geometry and hydrologic characteristics of the basin. When plotted on a map, these constants form patterns which delineate areas of different hydrologic characteristics from which future outflow can be calculated.

Equations and type curves have been prepared by M. I. Rorabaugh for ground-water outflow (a) from a finite aquifer for the conditions of recharge and constant downward leakage, and (b) for rectangular and circular aquifers for conditions of sudden or gradual recharge or sudden or gradual changes in river level.

Base flow computed from flow-duration data

R. W. Stallman has found that flow-duration data for streams having negligible delays in flow caused by surface storage can be analyzed to find the average annual base flow. Base flow computed from flow-duration data is markedly smaller than base flow computed by the usual hydrograph analysis. Dissimilarity between the two estimates of base flow is believed to be due to inadequate treatment of bank-storage effects in the hydrograph analysis.

Ground-water recharge and discharge in Wisconsin

Studies of ground-water levels and streamflow in the Little Plover River basin, Portage County, Wis., by E. P. Weeks and D. W. Ericson, indicate that most of the recharge to the glacial outwash and morainal deposits comprising the ground-water reservoir occurs in the spring. During the summer the discharge from the aquifers by phreatophytes and by irrigation wells may exceed recharge. During periods of extreme cold in the winter, water may be lost from the water table to the frost zone by vapor transfer.

Streamflow characteristics related to geology and topography in northern Michigan

G. E. Hendrickson has shown that in glacial-drift terrains in Michigan, streamflow characteristics can be related to the geology and topography of the watersheds. For example, in the Manistee River above Grayling, which has a drainage basin of 159 square miles consisting of 60 percent sandy glacial-outwash plains and 40 percent hilly moraines of silty glacial till, the ratio of maximum to minimum flows was only 2.1 in the 1962 water year. In contrast, this ratio was as much as 165 in the same water year in the Au Gres River above National City, which has a drainage area of 169 square miles consisting of only 20 percent sandy lake plains and 80 percent hilly moraines.

A low ratio of maximum to minimum flow indicates that the ground-water component of the streamflow is relatively large. A large ground-water component causes the water to have a low temperature and a high dissolved-oxygen content during the summer, conditions favorable to trout fishing.

Relations of surface water to principal artesian aquifer in Florida and southeastern Georgia

V. T. Stringfield (p. C164–C169) points out that the principal artesian aquifer of Florida and southeastern Georgia is the source of some of the largest springs known and the chief source of some surface streams where the aquifer is at or near the surface on two major geologic structures in Florida, and where it crops out in Georgia.

On the other hand, the surface hydrology is unrelated to the aquifer where the aquifer is far below the land surface in southeastern Georgia and in northeastern, southern, and western Florida. The surface streams there have a dendritic pattern with many tributaries in areas where they are independent of the aquifer, except on coastal Pleistocene terraces where the drainage pattern is influenced by topography left by the sea. Where recharge or discharge of the aquifer is sufficient to affect detectably the water table in the limestone or the piezometric surface, the streams have few tributaries, as in the Suwannee and Santa Fe basins in Florida.

Stream-induced ground water fluctuations

A method for analysis of ground-water fluctuations induced by irregular surface-water fluctuations has been developed by M. S. Bedinger and J. E. Reed (p. B177–B180). The method permits the estimation of the diffusivity (the ratio of transmissibility to coefficient of storage) where water-level fluctuations are caused mostly by changes in river stage. If the hydraulic characteristics of the aquifer are known, the methods can be an aid in the analysis of complex hydrographs where changes in river stage are one of several factors causing water-level fluctuations.

Base flow and stage related to seepage into reservoirs

J. F. Turner has evaluated interacting effects of lake stage and water-table elevation (as indicated by the base flow of a small stream) by developing linear relations between these factors and deviations from a mass-transfer calibration curve. The linear mass-transfer calibration was developed for Lake Michie, N.C., by relating the product of wind speed and difference between saturated and existing vapor pressure with the change in lake stage, adjusted for net outflow. The adjusted change in the lake stage is a measure of the combined rates of evaporation and seepage. The y-intercept of the calibration curve indicates the amount of seepage into the lake to be about 2.4 cubic feet per second. When the flow of Dial Creek near Bahama (drainage area, 4.71 sq mi) is zero, the seepage into the lake is about 2.2 cfs less than when the flow of the creek is 2 cfs. When the lake stage is 333 feet, the seepage is about 1.4 cfs less than when the lake stage is 340 feet.

Ground-water contributions to streamflow in Lake Erie–Niagara River basins

Study of the groundwater discharge into streams of the Lake Erie–Niagara River basins, New York, by A. M. LaSala, Jr., W. E. Harding, and R. J. Archer (1–64) indicated that streams crossing glacial sand and gravel deposits received the largest ground-water contributions. Also, streams crossing the Salina Group of Silurian age received large ground-water contributions. A gain of 3 cubic feet per second per mile of stream length was the largest observed. The poorest contributors were till, glacial-lake deposits, Silurian and Devonian carbonate rocks, and Devonian shale.

Differentiating sources of base flow

G. R. Kunkle, and E. C. Pogge have found that in Four Mile Creek basin, Iowa, the source of the base flow, which is derived from limestone and a sandy valley fill, can be differentiated by measurements of specific conductance of the streamflow.

Locks and dams on Ohio River increase yield of wells

Gerald Meyer reports that a rise in ground-water level during 1963 in alluvial deposits adjacent to the Ohio River at Kenova, in southwestern West Virginia, probably was caused by a rise in the navigation-pool stage of the river after the installation of the Greenup Lock and Dam by the Army Corps of Engineers several miles downstream in Kentucky. The water level in an observation well at Kenova rose 6 to 8 feet above normal levels. Also, the yields of public-supply wells at Ceredo, which adjoins Kenova, are reported to have increased after Greenup Dam was installed.

Flow of large springs in Florida computed from pressure in artesian well

Richard C. Heath reports the use of an artesian-pressure–discharge relation to compute the daily discharge for Silver Springs in central Florida. Artesian pressure is measured in a well tapping the Floridan aquifer, 4.2 miles southeast of Silver Springs, and discharge is measured in Silver Springs Run, 2½ miles downstream from the head of the springs. Records of artesian pressure from this same well were used to define a pressure-discharge relation for Rainbow Springs, 27½ miles west of the well. Measurements of the discharge of Rainbow Springs have been made at bimonthly intervals since 1931. By use of the pressure-discharge relation and correlation with discharge records for Silver Springs, mean monthly discharges for Rainbow Springs have been extended back to 1932, when the record of mean monthly discharges for Silver Springs begins.

Aquifer system provides flow to Muddy River, Nev.

Studies of the flow of Muddy River Springs, the principal source of flow of the Muddy River, a tributary of the Colorado in southeastern Nevada, indicate to T. E. Eakin and D. O. Moore (chapter D) that the spring flow represents the discharge from a regional aquifer system in Paleozoic carbonate rocks. They estimate the extent of the system at 7,700 square miles and conclude that 13 topographic basins in eastern and southeastern Nevada contribute ground water to the system. Preliminary analysis of minor long-term variations suggests a 15- to 20-year lag in response to recharge from precipitation.

SOIL MOISTURE AND EVAPOTRANSPIRATION

Evapotranspiration accounts for over 95 percent of the precipitation in arid regions, and even in the humid zone over half of the available moisture generally is removed in the vapor phase. Part of this moisture is used in the production of agricultural crops, trees, and forage; however, a significant portion is wasted as direct evaporation or in the growth of nonbeneficial vegetation. Studies of evapotranspiration are necessary to achieve a complete understanding of hydrology and to design and evaluate the effectiveness of watershed-management techniques. The soil serves an important function in the hydrologic cycle both as a moisture-storage reservoir and as a conveyance medium for the movement of water, either up for evapotranspiration or down for ground-water recharge. Evapotranspiration and soil moisture are sufficiently interrelated to require that both be considered in most evaluations of either.

Mathematical and analog analysis of soil moisture

Analysis of hysteresis-affected soil-moisture redistribution occurring after the cessation of rain was investigated by Jacob Rubin and resulted in a proposal for an empirical equation describing the pertinent hysteresis-affected relations of moisture content and suction. A digital computer program was prepared for predicting the moisture redistribution. Semianalytical mathematical methods developed in 1963 for estimating the lower bounds of rainwater uptakes at incipient ponding were extended to include the estimation of the upper bounds. This extended analysis also made it possible to make computations for soils having significant air intake.

R. W. Stallman developed an electric analog of steady flow in the unsaturated zone to compute the effect of depth to the water table on evapotranspiration loss from homogeneous media. The results show that evapotranspiration rates are highly dependent on depth to water table. The depth to the water table is regulated chiefly by the balance between recharge and evapotranspiration loss in extensive aquifers with low hydraulic relief.

Measurement of water flow through tree trunks

A new method has been developed by C. R. Daum for determining water use in large trees. The method is applied under almost natural conditions and is non-destructive. The procedure involves head, flow, and temperature measurements within the trunk. Hourly water use up to 4.4 gallons has been measured in a cottonwood tree in Arizona. He found an inverse relation between hourly water use and the diurnal variations in trunk radius as recorded on a dendrograph.

Evaporation from free water and transpiration by aquatic vegetation

In studies of the hydrology of prairie potholes in North Dakota, W. S. Eisenlohr found that the mass-transfer coefficient N described by G. E. Harbeck [90] included the effect of transpiration by emergent aquatic vegetation when present, and because of this the coefficient varied throughout the season in a pattern similar to one representing the amount of vegetative growth. J. B. Shjeflo in studying the water losses from prairie potholes found that there is very little difference in the amount of water used by a pond covered with emergent aquatic plants and one clear of vegetation. The reduction in evaporation from a pond covered with vegetation, due to shading and lower wind speed, is nearly counterbalanced by the transpiration of vegetation.

Evaporation from Lake Helene, a small lake in central Florida, amounted to 53.1 inches in 1962 and 51.3 inches in 1963, according to studies by R. B. Stone, Jr. The monthly rate of evaporation varied from 2.3 to 6.2 inches during the 2-year period. The mass-transfer theory was the basis for these determinations. Monthly mean temperatures of the water surface were always higher than the monthly mean air temperatures, even during the summer.

Evapotranspirometer studies

Intensive study of evapotranspiration by various types of vegetation under different climatic conditions were made by use of large soil-filled tanks or evapotranspirometers. During 1964, this method was continued at three sites to measure water use by phreatophytes.

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[90] G. E. Harbeck, 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory: U.S. Geol. Survey Prof. Paper 272–E.

On the lower Colorado River flood plain near Yuma, Ariz., 15 tanks were used to measure water loss by phreatophytes typical of the area. C. C. McDonald and G. H. Hughes report annual use of 106 inches by cattail (*Typha latifolia*) and 77 inches by arrowweed (*Pluchea sericea*).

In 6 evapotranspirometers, planted to saltcedar near Buckeye, Ariz., T. E. A. van Hylckama (1–64) found that a 50-percent drop in water use reported for July of 1962 did not occur again until August in 1963. This drop in water use could not be explained by the salinity of the water, carbon dioxide content of the air, or evaporation potential. Additional tanks were placed in operation in April 1963. It was possible in these tanks to measure water use by the hour. During hot weather, evaporation rate from bare tanks is reduced during the middle of the day. Two peaks were noted in the evaporation-rate curves, one in the early morning and one late in the afternoon.

Measurements of water use by four woody phreatophytes—willow, rabbitbrush, greasewood, and wildrose—grown in evapotranspiration tanks near Winnemucca, Nev., were continued by T. W. Robinson during the 1963 growing season (May through October). With the water level in all of the tanks maintained at 5 feet below the surface of the tank, willow (*Salix*) used the most water, followed by rabbitbrush (*Chrysothamnus viscidiflorus*), greasewood (*Sarcobatus vermiculatus*), and wildrose (*Rosa*). The use by willow, 4 acre-feet per acre, was nearly twice that of rabbitbrush and about 3 times that of greasewood and wildrose. It was found that willow used 50 inches, about the same amount of water as evaporated from a Weather Bureau class A pan and more than 5 times the 9 inches evaporated from a bare soil tank in which the water level stood 2.5 feet below the surface. Cover density in the willow tanks was about 90 percent, in the rabbitbrush and greasewood tanks about 50 percent, and in the wildrose tanks about 70 percent.

Evapotranspiration by riparian vegetation

Studies in the Piedmont province of Georgia by W. H. Norris indicate that diurnal fluctuations of streamflow due to variation in evapotranspiration rate may be detected in streams with flows up to 100 cubic feet per second. The magnitudes of the maximum fluctuations were found to be related to the magnitudes of the concurrent daily minimum flows. This relation may be used to estimate diurnal variations likely to occur at sites on streams where special equipment has been installed for the purpose of indicating minimum flows. It was also found that the time of occurrence of the minimum flows of the diurnal cycles is related to size of drainage area, magnitude of daily mean flow, and time of year. The larger the drainage area and the smaller the daily mean flow of a specific stream, the later in the day the minimum flow tends to occur. Also, the minimum flow tends to occur progressively later in the day as the season progresses during the year.

Evapotranspiration by phreatophytes on the Gila River flood plain, San Carlos Indian Reservation, Ariz., is being measured by a water-budget study. R. C. Culler and R. M. Myrick found that during the dry months of May, June, and July, the water table was lowered an average of 2.5 feet. For this period the change in water storage within the saturated and unsaturated zone, as measured by neutron soil-moisture meters, ranged from 12 to 18 inches. During the summer storm period, August and September, the depletion of the surface flow of the Gila River to evapotranspiration and ground-water recharge was about 8,000 acre-feet. Depth to the ground-water table on the area of phreatophytes ranges from 6 to 45 feet. For all soil profiles having a depth to water table greater than 10 feet, the change in moisture storage during the summer was confined to 2 strata: the surface 2 feet representing the moisture received from precipitation, and a zone 5 feet thick where roots deplete the water in the capillary and saturated zone.

Water savings by modification of riparian vegetation were measured in Cottonwood Wash, Mohave County, Ariz., by J. E. Bowie and William Kam. Measurements of streamflow, ground-water levels, vegetation, and meteorological phenomena obtained in a subdivided (2.6 and 1.5 miles) 4.1-mile reach of the channel and flood plain defined the use of water by riparian vegetation under natural hydrologic conditions. Subsequent defoliation and eradication of the vegetation in the lower subreach permitted the determination of the change in water use as a result of the modification. The computed average loss in the lower subreach for the 8-month growing season before modification was 80 acre-feet, which represented about 18 percent of the average flow entering the reach. The average loss after modification was 42 acre-feet, which represented about 12 percent of the average flow entering the reach.

Evapotranspiration from the low terraces and flood plain along the middle part of the Big Sandy Creek valley, Colorado, is greater than 94 thousand acre-feet per year. D. L. Coffin reports that this is 4 percent of the average annual precipitation on the entire basin. Even though this is a relatively large part of the available water supply, there has been no permanent lowering of the water table.

F. W. Kennon reports that a 48-hour study of water losses from a small flood-retarding reservoir in central Texas indicated that evapotranspiration losses from reservoir borders was inducing an outward seepage equal in amount to water loss from evaporation at the free water surface of the reservoir.

Areal application of soil-moisture studies

Studies of soil moisture by W. H. Norris in a small basin in the Piedmont province of Georgia indicates that during periods of average rainfall, water requires several months to percolate through the zone of aeration to the zone of saturation beneath the ridges on the perimeter of the basin. The water table beneath these ridges is about 30 feet below the surface. During rainless periods, the loss of stored water in the soil due to evapotranspiration and percolation may constitute the largest transfer of water in the basin. For example, the calculated decrease in soil moisture stored above the zone of saturation during a 2 week period of base-flow recession in October 1963 was 5 times as great as the concurrent discharge of the stream draining this basin.

Overbank flooding and soil moisture

The influence of increased channel capacity on soil moisture and associated range-forage plants on flood-plain soils was studied by R. F. Miller, F. A. Branson, K. R. Melin, and I. S. McQueen. Periodic observations near Fort Peck, Mont., have been made since 1947 in the Willow Creek valley, which is underlain by alluvium derived from shale. Rapid advances by a series of headcuts up a previously small channel and widening of the resulting trench were observed. Channel conveyance is increased by erosion, and the frequency of overbank flooding decreases; the resulting changes in depth, degree, and frequency of soil wetting induce changes in soil chemistry and structure, as well as quantities and species of plants present. Individual soil characteristics were found to assert more influence on soil-water-plant relations as the effect of flooding diminished.

Accumulation of boron by phreatophytes

In the course of studies of water use by woody phreatophytes near Winnemucca, Nev., T. W. Robinson found that greasewood (*Sarcobatus vermiculatus*) was responsible for yearly enrichment of soluble boron salts in the surface and near surface soils. Chemical analysis of samples of the soils and leaves indicates that this was accomplished by absorption of the boron through the roots and by translocation to and concentration in the leaves; the boron is released later on the surface of the soil, as the fallen leaves decay. The soluble boron content in the soil profile was greatest in the first 2 feet, ranging from 13 to 32 parts per million, then decreasing rapidly to less than 1 ppm in the 5- to 8-foot depth. Boron content in the leaves increased rapidly in the early part of the growing season from 22 ppm in mid-May to 130 ppm in mid-July. The areal distribution of boron in the top 3 inches of soil, in the vicinity of a mature plant with a crown diameter of 2 feet, was greatest near the main stem. At a distance of 1 foot it was 15 ppm, decreasing to 11 ppm at 6 feet and to essentially zero at 8 feet.

SEDIMENTATION

The area of investigation termed "sedimentation" includes the sequence of events which begins with the separation of particles from parent rock and concludes with their consolidation into another rock. Sedimentation, therefore, involves consideration of sediment sources; of the erosion, transportation and deposition of sediments; and of environments of deposition and sedimentary deposits. The subject is of special interest to engineers who are primarily concerned with problems of erosion, transportation, and deposition of sediments, and to geologists who are concerned with interpreting the origin of sedimentary rocks and the origin and modification of landforms. Two reports published during fiscal year 1964 illustrate these two approaches. The first, "Fluvial Sediments—A Summary of Source, Transportation, Deposition, and Measurement of Sediment Discharge," by B. R. Colby (1–63), is largely a summary of the engineering literature on sediment transport in rivers. The other, "A Tentative Classification of Alluvial River Channels," by S. A. Schumm (1–63), is an attempt to classify river channels on the basis of sediment load and channel stability; it is mainly a geologic approach to the problem.

The background and interests of those engaged in sedimentation research are reflected in the diversity of the results reported by scientists of the Geological Survey. These results are presented under the following major subdivisions of the subject: erosion, transportation, and deposition.

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EROSION

The extent and rate of erosion within a drainage basin can be estimated by measurement of the sediment transported by the streams draining the area. However, to gain some understanding of the progress of erosion on a hillslope or in a channel, repeated measurements are necessary. For example, surveys made by R. K. Fahnestock along the Wynoochee River in Washington show that cutbank migration of from 10 to 20 feet and alteration of the form of point bars were the results of a single flood of relatively small magnitude.

Repeated measurements in an ephemeral stream channel near Santa Fe, N. Mex., by L. B. Leopold and W. W. Emmett, indicate a general balance between erosional and depositional processes in the channel. Although the measurements show an average of 0.10 to 0.20 feet of aggradation during 6 years of observation, annual scour, which temporarily deepens the channel as much as 1.5 feet, may occur during flash floods. Five years of experimentation with painted cobbles in the same channel show that a close spacing of particles makes them less easily moved than when they are spaced far apart. W. B. Langbein has checked these observations experimentally by the use of glass beads in a small flume.

TRANSPORTATION

Predicting sediment loads of rivers

One of the primary goals of those concerned with the movement of sediments through river channels is the development of criteria whereby the total sediment load can be estimated either on a short- or long-term basis. Measurements of total sediment load on Fivemile Creek, Wyo., were used by D. C. Dial to relate total sediment load to measured load using the modified Einstein procedure. Individual measurements show considerable variation in the ratio between total load and measured load; however, at high sediment concentrations, it was found that lower ratios between total load and measured load occur. This happens because the unmeasured portion of the sediment load generally is a smaller percentage of the total load when the concentration is high. A weighted-mean ratio based on concentration or measured load should improve the prediction of total loads.

C. F. Nordin, Jr., J. P. Beverage, and J. K. Culbertson, after applying sediment-transport formulas to field data for the Rio Grande in New Mexico, conclude that, although no proposed relation is satisfactory in all respects, several methods give reasonably reliable results for shallow flow in sand-bed streams. In general, the formulas which relate sediment transport to the total shear stress on the bed are unsatisfactory, because they indicate a constant concentration of bed material in transport. The formulas which relate transport to effective shear stresses yield transport rates which are low at low shear stresses and are too high at high shear stresses. These discrepancies are due to experimental conditions under which the relations were derived and to some of the basic assumptions adopted in the derivations of the formulas.

H. P. Guy and D. B. Simons (2–64) conclude from flume studies that velocity and sediment-concentration distributions in a cross section can be predicted only within crude limits. Sediment discharge in a stream should be computed from a velocity-weighted concentration obtained by sampling at several points or verticals in the stream cross section. Spatial sediment concentration should be measured when information on either the actual load or amount of sediment exerting pressure on the bed is required. Theoretical and measured differences between spatial and velocity-weighted concentrations show that spatial concentrations are normally greater.

H. E. Reeder has found through analysis of records collected for 11 years on the Yadkin River, N.C., that annual sediment yields in tons per square mile can be estimated for the basin above Yadkin College if annual water discharge is multiplied by 4.15×10^{-4}. He reports that the estimates are sufficiently accurate for design and planning purposes.

Computing sediment yield from geomorphic parameters

A means of estimating long-term sediment yields in the absence of hydrologic data is through a quantitative geomorphic approach. L. K. Lustig (1–64) has used this method to estimate the sediment yield from the Castaic watershed in California. Using six drainage basins in the San Gabriel Mountains for which long-term sediment-yield data are available, he established significant relations between sediment-yield and the following geomorphic parameters: drainage area, mean-ground slope, total stream length, bifurcation ratio, stream frequency, and channel-slope ratios. On the basis of these relations, Lustig estimated the sediment yield of the Castaic watershed to be about 250 acre-feet per year.

Dissolved and suspended load in United States rivers

Analysis of records of dissolved load in rivers of the United States lead W. B. Langbein and D. R. Dawdy to conclude (chapter D) that the dissolved load carried by rivers increases directly with the amount of runoff only up to about 3 inches of runoff. The load increases less rapidly in those rivers whose runoff exceeds 3 inches, and it attains a generalized maximum of 150 tons per square mile per year in rivers having a runoff in excess of 10 inches. The dissolved load carried by rivers is commonly less than the suspended load, but the proportion increases with the humidity of the climate. In dry climates, less than 10 percent of the total load may be carried in solution, whereas in humid climates the percentage may be 50 percent or more.

VARIABILITY OF SEDIMENT LOADS IN RIVER

The difficulties in obtaining accurate prediction of sediment loads can best be understood by considering those rivers for which sediment loads have been measured under different conditions.

Sediment load in Columbia basin

Obviously sediment loads will vary greatly depending on water discharge through the channel. For example, W. L. Haushild, H. H. Stevens, Jr., and G. R. Dempster, Jr., report from studies in the Columbia basin that in the Columbia River in Washington and Oregon most sediment is transported as suspended load and that suspended sediment loads ranged generally from 1 to 20 parts per million, during low and medium flow, and from 50 to 90 ppm, during high discharge. Peak concentrations as high as 2,700 ppm have been measured, following storms, in the Snake River basin. It is interesting to note, however, that the particle-size distributions of bed material did not change significantly with time or discharge at the cross sections where measurements were made. Appreciable amounts of bed material are transported only periodically in much of the area because the streams are not capable of coarse-sediment transport except during high flows.

Rapid snow melt produces great load

The sediment loads of rivers can show marked fluctuations depending on the antecedent moisture conditions or prewetting of the soil. An example is reported by B. E. Mapes and P. R. Boucher from Washington. On February 2, 1963, the ground in eastern Washington was covered with 4 to 8 inches of snow, and was frozen. On February 4, the temperature had increased to about 60°F, and some rain fell during the period. Rapid melting of the snow occurred on February 3 and 4, and additional rain, as much as 1 inch, fell on February 4. The soil, although still frozen at depth, was saturated at the surface, and severe erosion and flooding resulted. The sediment yield following the short but intensive rainfall was 150 to 200 percent greater than that during the previous 2-day period, yet it was removed by 10 to 16 percent less runoff. The Palouse River at Hooper, Wash., transported 2.1 million tons of sediment in 31,100 acre-feet of runoff on February 5, whereas only 672,000 tons was transported by 47,300 acre-feet of runoff on February 4.

Urbanization and sediment load

The effects of urbanization on the sediment load of a river are clearly demonstrated in a study of the urban hydrology of the Northwest Branch of the Anacostia River in Maryland by F. J. Keller, D. H. Carpenter, and C. A. Richardson. They report that prior to the urban development in the basin the highest measured suspended-sediment concentration was 6,500 parts per million, whereas concentrations in excess of 40,000 ppm are now measured. The high sediment concentrations precede the peaks of water discharge by several hours.

Timber downfall produces high sediment load

P. A. Glancy reports an excessively high sediment yield from streams of the Chehalis River basin in eastern Washington. About one-quarter million tons of suspended sediment was transported from the basin by about 394,000 acre feet of discharge during 5 days, during and following the storm of November 19 and 20, 1962. The Satsop and Wynoochee Rivers contributed only 45 percent of the runoff but 88 percent of the sediment. The excessive sediment yields were attributable in part to an abnormal amount of timber downfall, resulting from a violent windstorm on October 12, 1962.

Effect of confining banks on transport

Sediment transport is also influenced by other variables such as channel dimensions and water temperature. Bed-material transport relations at 6 sediment stations, along a 110-mile reach of the Rio Grande in New Mexico, were investigated by C. F. Nordin, Jr., and J. P. Beverage, who found that the transport relations fell into two groups. One group represented stations with confining, or partially confining banks, and the other group represented stations without lateral restrictions. At low flows there was greater bed-material discharge at the confined sections, while at high flows there was greater bed-material discharge at the unconfined sections. Flow characteristics were compared between pool-and-riffle and sand-bed channels. For the pool-and-riffle channel, the depth, water-surface slope, bed-shear stress, flow resistance, and median bed-material size increased with increasing water discharge. For the sand-bed channel, water-surface slope and bed-material characteristics were approximately constant, while flow resistance decreased and bed-shear stress increased conservatively with increasing discharge.

Sediment transport in Sierra Nevada

Sediment transport studies by R. J. Janda indicate that little sediment is currently supplied to the Middle Fork of the San Joaquin River above 5,000 feet altitude because most of the runoff results from snowmelt. Most of the gravel observed on the streambed evidently is a lag deposit. Below 5,000 feet altitude, differences in the character of the flood flows, coupled with the normal downstream increase in mean velocity, result in higher flow velocities and increased stream competence. In these reaches, boulders up to 400 mm in intermediate diameter are found in splay deposits lying on root-masses of willows.

DEPOSITION

It is difficult to determine in which category some of the results of sedimentation research belong. Investigation of ripples, dunes, and similar bed features are here classified as depositional studies, even though the materials involved may be in transport when the features are studied.

Mathematical model to predict ripple index

J. F. Kennedy (1–64) has used a mathematic model, developed during an analysis of the stability of the fluid-channel-bed interface, to predict the velocity, amplitude, and wave length of ripples formed in closed rectangular conduits and in the desert. Good agreement was also found between predicted and observed values of ripple index (ratio of length to height).

Large-scale study of dunes

Three types of modern dunes—barchan, parabolic, and transverse—were studied on a large scale by E. D. McKee by cutting two trenches through a typical dune of each type with bulldozers. The details of the stratification were recorded with photographs, grid plotting, and latex peels. Comparisons should ultimately be possible between the dune structures examined and the cross strata in various ancient formations, such as the Navajo and Coconino Sandstones.

Wave-tank studies of ripple marks

In another study reported by E. D. McKee, a wave tank was used to investigate climbing ripple marks. The results demonstrate a close interrelation between various structure types, which are commonly interpreted from well cores as resulting from different environments and contrasting processes. The following conclusions were obtained: (1) The amount of ripple climbing is controlled by the rate of sediment feeding, (2) the range in form and shape of ripple marks is determined by differences in water depth, wave length, wave speed, and grain size, and (3) the evolution of ripple type in both vertical and lateral position, within a sequence of deposits, is controlled by progressive changes in factors that determine the variety of ripple mark.

Suspended sediment and fish-egg survival

Studies by A. R. Gustafson of the U.S. Geological Survey and D. R. Bianchi of the Montana Fish and Game Department show that suspended-sediment discharge, stream discharge, velocity through the bed gravel, and dissolved oxygen are important factors in affecting survival of rainbow and cutthroat trout eggs. Sediment settling into a redd or spawning ground caused decreases in the permeability of the gravel and the velocity of the interstitial water. When the suspended-sediment passing over a redd reached an accumulated total of 60 or more tons, the seepage velocity showed a perceptible decrease. As the accumulated total suspended-sediment load increased progressively beyond this level, there was a corresponding decrease in the seepage velocity. Redds exposed to an accumulated load of 290 tons of suspended sediment had the highest egg mortality. Redds with the lowest suspended-sediment load, highest seepage velocity, and the highest dissolved-oxygen concentration had the greatest egg survival.

Upstream effect of barrier structures

When a structure is placed in a stream channel, downstream effects can be expected, but commonly upstream effects can be measured also. G. C. Lusby reports that 3 years after construction of a barrier dam across the channel of Sheep Creek, Utah, to decrease the sediment contributed to the Paria River, no material smaller than sand was being deposited in the reservoir, and that material larger than sand was being deposited at the upstream end of the reservoir above spillway level. At the end of 1962 the dam had caused deposition of 128.9

acre-feet of sediment, 32 percent of which was above spillway level.

Before the dam was built, the channel gradient was about 1.63 percent. After construction, the gradient on the upper end of the sediment deposit was 0.93 percent.

Storage of fine material in islands and point bars

C. F. Nordin, Jr., and J. P. Beverage (3–64) find that the islands and point bars in the channel of the Rio Grande contain as much as 20 percent surficial sediment finer than 0.062 mm, which is deposited during receding flows. They conclude that temporary storage of this fine sediment, which is flushed during high flows, accounts for some of the scatter noted in discharge–sediment-transport relations.

Sedimentation in Mammoth Cave

C. R. Collier and Russell F. Flint (1–64) resurveyed 13 lines across passageways in Mammoth Cave, Ky., that are subject to flooding from the Green River. They determined that numerous low flows had deposited 0.5 foot of sediment in the lowest levels. However, three subsequent higher flows removed this sediment but at the same time caused thinner deposits to form at higher levels.

Bedforms under varying flow conditions

As the hydraulic character of flowing water changes, a significant change also occurs in the type of sedimentary features to be found on the bed of a stream. For example, R. K. Fahnestock and Thomas Maddock, Jr. (p. B140–B142) report that their studies in two 1,600-foot reaches of the Rio Grande near El Paso, Tex., show that bedforms range from dunes to a plane bed in a 100-foot-wide reach, whereas under the same discharge, dunes and prominent bars were always present in a 200-foot-wide reach. Investigation in March and August showed that the change in water temperature of about 35°F significantly affected the hydraulics of flow and bedforms. For example, at similar discharges, mean velocity was greater in March, and in the 100-foot-wide reach the bed was plane; whereas mean velocity was less in August, and large dunes developed in the 100-foot-wide reach.

Flume studies of bed configuration

Laboratory-flume studies by J. F. Kennedy showed that the bed configuration changed from ripples to dunes in the relatively narrow range of shear velocity of from 0.12 to 0.14 feet per second—independent of the median particle size of bed material and depth of flow.

Stratification in streambed deposits

Observations of fluvial stratification made in shallow trenches cut through bars near El Paso, Tex., led R. K. Fahnestock and J. C. Harms (Marathon Oil Co.) to conclude that large-scale trough cross-stratification is related to dune migration; small-scale cross-stratification is related to ripple migration; and tabular cross-stratification is related to migration of bars. All types formed in the lower flow regime. However, horizontal stratification, related to plane-bed sediment transport, is formed in the upper-flow regimes. The most significant point illustrated by their study is that stratification is the product of many complexly interrelated variables, and, for this reason, interpretations of environment from stratification in terms of single variables, such as depth, velocity, or slope are unrealistic and misleading.

Regional heavy-mineral trends in Colorado Plateau

R. D. Cadigan found that the regional linear trends in ratios of abundance of specific heavy minerals in the Morrison Formation of the Colorado Plateau region are controlled by three main factors, namely, (1) the size and areal distribution of source areas, (2) rate of burial of the minerals, and (3) relative rate of attrition of the minerals. Trends of decreasing abundance of certain minerals are the effects of relative rates of deposition of the minerals and the effects of losses of certain minerals, due to chemical attack by interstratal solutions during diagenesis. The effects of the losses may be conveniently combined in the term "attrition." The overall effect of differential attrition on regional trends of mineral ratios is to produce reverse trends for the more resistant minerals.

Loss by attrition of nonopaque heavy minerals in the Morrison Formation sediments is evidently greater for the minerals garnet and staurolite than for zircon, tourmaline, rutile, and apatite. Garnet and staurolite grains show much evidence of volume loss by solution action (etched and characteristically embayed surfaces). The other minerals show only effects of abrasion. Although there are complicating factors of different sources, garnet and staurolite ratios show linear trend surfaces which dip northward and eastward, the "downstream" direction, which is almost opposite to trend surfaces of zircon and rutile ratios which slope southward and westward. The regional trends of the ratios of durable minerals are thus mathematically dependent on the degree of differential attrition in the less durable minerals and may, as in this instance, tend to slope upstream instead of downstream.

Beach and eolian sands indistinguishable at Cape Cod

Studies of suites of beach and eolian sands of Cape Cod, Mass., by John Schlee, Elazar Uchupi, and J. V. A. Trumbull (chapter D) indicate that these environments cannot be distinguished locally on the basis of grain-size parameters. Evidently, factors relating to original source, in this case glacial debris, overshadow the effects of local sorting by the transporting medium.

Estimating glacial-drift lithology from pebble measurements

C. S. Denny and A. W. Postel (p. B143–B145) have developed a rapid method of estimating glacial-drift lithology or the proportion and size of stones of various rock types in the coarse fraction of glacial drift. One hundred pebbles are selected at intervals along a measuring tape laid on the surface of an outcrop. Surface samples selected in this manner and bulk samples of the same deposit yield generally similar results. Denny and Postel conclude that a surface sample collected by this method characterizes the stones on the surface of the till, and, provided that the proportions of the various rock types do not change at depth, the sample will be representative of glacial drift lithology.

Shape factor for gravel-size fragments

A new shape factor for gravel-size sedimentary particles has been developed by G. R. Alger. This factor includes the effect of surface area, which was measured using fluorometer equipment. Using this parameter, one can more acceptably model the behavior of freely falling particles of sediment.

LIMNOLOGY

Limnological investigations of lakes and streams contribute to an understanding of the factors controlling water composition, processes involved in transport and deposition of materials, and the use of aquatic organisms as hydrologic indicators. Data from the fields of physics, chemistry, geology, biology, and meteorology are synthesized to interpret conditions observed in natural waters. Laboratory studies, conducted under controlled conditions, also are being employed for the solution of hydrologic problems.

Temperature, chemistry, and algal growth in a lake

In studies of Pretty Lake, LaGrange County, Ind., J. F. Ficke and R. G. Lipscomb found a close relation between water temperature, chemical character, and algal growth. From the free-circulation condition which existed after ice breakup in 1963, the lake quickly became thermally stratified owing to rapid surface heating. Wind action erased the early stratification, and a permanent thermocline was established 3 days later. As a result, the temperature of the lake's deepest point (82 feet) during the summer of 1963 was about 2°C higher than it would have been if the original stratification had remained. Surface temperatures ranged as high as 28°C in July and August 1963; the bottom-water temperature never rose above 8°C (in November).

Specific-conductance values of 280 micromhos in the upper water and 320 at the lower level, and bicarbonate increases from 140 parts per million to 176 ppm, respectively, indicate the degree to which thermal stratification influenced chemical distribution. Silica concentrations measured in October increased with depth from 1.4 ppm at the surface to 3.7 ppm at 42 feet, with a maximum of 5.5 ppm at 67 feet, corresponding to differences in diatom growth rates at different levels in the lake.

In late August when the temperature profile showed marked stratification from 22°C in the top 20 feet to less than 12° C below a 35-foot depth, with a transition zone between, algal counts were about 37,000 cells per liter, and dissolved-oxygen concentration was about 8 ppm in the warmer water. In the transition region, dissolved oxygen decreased rapidly (3.6 ppm at a 25-foot depth to zero at 30 feet), while the algal population was unusually high (92,000 cells per liter) at 25 feet and decreased to 30,000 cells per liter at 30 feet. Among the diatoms and the bluegreen algae, *Cyclotella* (d.) and *Aphanizomenon* (b.g.) were the dominant forms during August. By late October the association had changed to *Asterionella* (d.), *Gomphosphaeria* (b.g.) and *Aphanizomenon*. At the time of the fall overturn, *Cyclotella*, *Anabaena* (b.g.) and *Aphanizomenon* had become the dominant forms. After the autumn circulation of water in the lake, total algae measured about 15,000 cells per liter, and the dissolved oxygen was about 8 ppm throughout the water column.

Vertical density currents in Lake Zürich

From published reports on the algae and varved sediments in Lake Zürich, Switzerland, and from laboratory experiments, W. H. Bradley has established that vertical density currents exist and have properties which help explain processes observed in the Swiss lake. Vertical density currents are new to hydrodynamics. Experiments show that such currents are capable of moving fine particles or microorganisms from the surface waters of lakes to the bottom as much as 55 times faster than if the particles settled according to Stokes' law. The difference in rate of fall between those indicated by Stokes' law and those moved by vertical density currents probably depends on the population density of the particles.

Water quality of western Lake Erie

Studies in western Lake Erie by G. W. Whetstone during August and September 1963, showed nearly isothermal conditions with little vertical stratification of major solutes. However, a north-south difference in solute concentration was noted in the 30-mile reach from Colchester, Ontario, to Toledo, Ohio. Dissolved-solids content ranged from 140 to 200 parts per million, with the lowest concentrations on the Canadian side. Similarly, chloride values ranged from 13 to 26 ppm with high concentrations extending over a distance of 13 miles from Toledo, and low concentrations occurring near the Canadian shore. Phosphate increased from 0.1 ppm at Colchester to 0.2 ppm at a point 12 miles from Colchester, to 0.4 ppm at Toledo. Nitrate concentrations of the lake water ranged from 0.8 to 1.5 ppm, with higher concentrations observed near the center of the lake and in Maumee Bay near Toledo. The dissolved-oxygen content of the lake water was remarkably uniform, ranging from 8.2 to 9.4 ppm.

Dissolved-mineral inflow to Great Salt Lake

About 2 million tons of dissolved salts are discharged by streams, canals, drains and springs to Great Salt Lake, Utah, each year. A study by D. C. Hahl and R. H. Langford confirmed results of a preliminary report by Diaz [91], which revised upward the earlier estimates of dissolved-mineral inflow to the lake, and established that this annual inflow is equal to about 0.05 percent of the 4.4 billion tons of salts dissolved in the lake brine. Although this load delivered by surface streams does not take into account the mineral matter contributed by ground water, it is believed to represent about 80 percent of the total dissolved load contributed to the lake. Most of the average annual inflow of 1.9 million tons for the water years 1960 and 1961 was contributed by the Bear River and by drains and sewage canals around the lake. The Weber and Jordan Rivers and streams draining the intervening mountain front together contributed about one-fifth of the load. Springs around the lake contributed slightly more than one-sixth of the mineral load.

Great Salt Lake brine contained about 24 to 28 percent by weight of dissolved solids during the 2-year study (1959–61). During the last century the dissolved-solids concentration of the brine has ranged from about 15 percent in the 1870's when the lake stage was high, to about 28 percent in the early 1900's and 1960's when the lake was very low. Despite the fluctuation in concentration, the chemical character of the solution has remained practically constant over the years.

Mineral transport in Great Salt Lake

In the late 1950's a causeway of permeable, quarry-run, rock fill was constructed separating the northern one-third of Great Salt Lake from the main body of brine. The fill has two culverts, each 15 feet in width, which allow free flow of brine in about the upper 10 feet of the 25-foot-deep lake. Because about 95 percent of the total inflow (about 2 million acre-feet) enters the southern two-thirds of the lake, expected brine movement should be from the southern to the northern arm. Inflow is at a peak during the spring and is relatively small during the summer months when evaporation is the greatest. Therefore, after the spring inflow has equalized between the two arms of the lake, flow through the culverts should be small during calm weather. During the fall of 1963, observations by D. C. Hahl, M. T. Wilson, and R. H. Langford showed that the upper 4 feet of water in the culverts was flowing northward, while the lower 5 feet was flowing southward. It is tentatively concluded that density differences coupled with small head differences can cause opposing flows to occur simultaneously through the fill. The study of mineral transport in Great Salt Lake is further complicated by recent observations that tributary waters and local precipitation tend to spread out on the surface for long distances before mixing with the brine.

Distinctive chemical character of three lakes in Oregon

Goose, Summer, and Abert Lakes, in south-central Oregon, form a chemical sequence of distinctive character, according to A. S. Van Denburgh. The three lakes occupy topographically enclosed basins and serve as long-term accumulation sumps. The dissolved-solids content of water from each of the three averages 1,000 parts per million, 7,000 ppm, and 50,000 ppm, respectively, and consists chiefly of sodium, carbonate-bicarbonate, and chloride. Calcium and magnesium, two normally abundant constituents in water, are nearly absent; only sodium, chloride, and bromide undergo long-term enrichment in the lakes. During long-term salt accumulation within the lake, most constituents of surface inflow are depleted through precip-

[91] A. M. Diaz, 1963, Dissolved-salt contribution to Great Salt Lake, Utah: U.S. Geol. Survey Prof. Paper 450–E, p. E163–E165.

itation, alteration, biologic utilization, or other processes.

The shallowness of the lakes allows thorough mixing and homogenization so that the dissolved-solids content is consistent throughout each of the three. Hence, the concentration of the water is related to the depth of water in the lakes inasmuch as the total dissolved load remains nearly constant over short periods.

Effect of tree leaves on water quality

In a study of the effects of tree leaves on water quality, K. V. Slack found that masses of leaf-litter in pools during low flow of autumn resulted in higher solute concentrations and greatly increased water color in the North Fork Quantico Creek, Va. Although low silicate concentrations in some pools resulted from diatom uptake, most dissolved minerals increased markedly after leaf-fall began in late September. The greatest increases occurred during October, and maximum effects were observed in pools containing the largest amounts of decaying organic material. For example, between October 3 and 27, the station with the heaviest organic load showed the following changes: calcium and bicarbonate concentrations tripled, free CO_2 doubled, total iron increased fivefold to 2.7 parts per million, and manganese soared from 0.1 to 4.8 ppm. Dissolved-oxygen concentrations decreased to near-zero values, resulting in a partial fish kill. Sulfate concentrations decreased during October but increased sharply when flow was restored by a rise in early November. Thereafter, manganese dropped to around 0.02 ppm, total iron to about 0.5 ppm, and sulfate to 7 ppm. These observations help explain the occurrence of a black manganese- and iron-rich coating on the rocks in this stream. The deposit occurs as a narrow band only along the center of the channel, indicating that it is a low-flow phenomenon. Leaching of manganese and iron from tree litter in shallow pools can now be assigned a major role in development of the black coating, which is not removed by subsequent high flows.

Water quality related to leaves of five tree species

Laboratory studies by K. V. Slack and H. R. Feltz of the effects of five different species of tree leaves on composition of natural waters indicate that maple-leaf cultures developed the greatest color and beech the least. At the end of three weeks, the following color intensities were measured: Maple, 650; tulip poplar, 600; scarlet oak, 500; dogwood, 300; beech, 50; compared with the blank which remained at 20 units.

Significant changes in dissolved mineral content occurred in some species within the first 24 hours. Oak is apparently the most resistant species to the leaching effects of water, exhibiting a maximum change of 5 micromhos in 3 weeks. Both iron and manganese increased in all cultures. Total-iron concentrations were lowest in beech and highest in oak and tulip poplar cultures. Manganese was lowest in beech and dogwood and highest in oak and maple cultures. Major contributors to increased solute content are calcium and magnesium bicarbonate and sodium and potassium bicarbonate. Dissolved oxygen decreased rapidly to values near zero in all leaf cultures.

Biological control of minor-element concentration

In a recently completed survey of the minor-element content of waters of California, W. D. Silvey found that the percentage of minor elements was fairly uniform, even for waters draining different lithologic environments. However, as biological activity increased, the concentration of minor elements decreased, reaching a minimum in sea water. When duckweed (*Lemna*) was allowed to decompose in samples of American River water in the laboratory, the concentrations of aluminum, iron, manganese, and titanium increased by an average factor of 382,000. Concentrations of cobalt, copper, nickel, and vanadium increased by an average factor of 33,000 over the amounts present in the original water. Failure to observe large increases in minor-element concentration in natural water following seasonal die-off of aquatic plants is attributed to sinking of dead organic material, resulting in concentration of minor elements in bottom sediments, and the existence of an equilibrium between biological processes and available nutrients. It is tentatively concluded that additional nutrients released by decay increases productivity until a new equilibrium is established.

Effect of forest fire on stream water

Water samples from streams and springs in and near the burn area were collected immediately after a fire on about 39,500 acres in Tahoe National Forest, Calif. Contrary to expectations, no significant changes in percentages of dissolved constituents were found by C. E. Roberson and J. H. Feth, who conducted the study in cooperation with the Pacific Southwest Forest and Range Experiment Station. They concluded that future evaluation of the effects of burning on forested areas should include careful prior planning and possibly use of controlled fires on study plots.

GEOMORPHOLOGY

Paleohydrologic studies at Russell Cave, Ala.

The rock shelter at Russell Cave National Monument has been studied by J. T. Hack during reexcavation. An exposed stratigraphic series indicates a cold climate prior to 9000 before present, followed by deposition of flood deposits ending in 5500 B. P. which were rich in cultural remains. From that date to the Columbian period, roof disintegration provided an upper fill, the climatic implications of which are still being studied.

Erosion rates and processes

The exposure of roots of long-lived trees in the White Mountains, Calif., has been interpreted by V. C. LaMarche, Jr., (1–63) in terms of rate of slope denudation. Significant differences in denudation rate of contrasting slope types on the same lithology cannot be entirely explained by differences in slope angle.

Rates and processes of hillslope erosion studied by S. A. Schumm and R. J. Chorley provide some indication of the rate of cliff retreat in the Colorado Plateau. The general scarcity of talus at the foot of major scarps appears to be caused by the relatively rapid disintegration of the fallen rock rather than by the cessation of scarp retreat in post-Pleistocene time.

In a related study, R. F. Hadley has shown that slope aspect is one of the determinants of the frequency of freezing and thawing. The freeze-thaw events were 2½ times more frequent on a south-facing slope in an area studied near Denver, Colo. This greater frequency appears to make the south-facing slope more susceptible to sheet erosion than slopes having other exposure.

Slope development

Various mathematical models of slope development investigated by A. E. Scheidegger appear to support the thermodynamic analogy proposed by Leopold and Langbein.[92]

Morphology of stream channels

W. B. Langbein (p. B119–B122), drawing an analog from thermodynamic entropy postulates that river-channel equilibrium represents the most probable condition between two opposing tendencies. There is on the one hand the tendency for minimum total work in the stream-channel network, and there is also an opposing tendency for uniform distribution of work rate in all parts of the system. These considerations allow a theoretical derivation of the exponents of the hydraulic geometry not only for the downstream case but for the at-a-station case as well in natural rivers. It further allowed the derivation of the Lacy equations for stable irrigation canals with self-formed cross sections (Langbein, 1–64).

A detailed study of braided channels carrying glacial-outwash gravel has been published by R. K. Fahnestock (1–63). Hitherto unmeasured details of channel change in a braided gravel-bearing stream emphasize the rapidity of channel alterations. These alterations have both seasonal and daily fluctuations associated with changes of rate of glacial melt.

[92] L. B. Leopold and W. B. Langbein, 1962, The concept of entropy in landscape evolution : U.S. Geol. Survey Prof. Paper 500–A.

PLANT ECOLOGY

Plants and the hydrologic and physical environment are intimately related—plants intercept water, use it, modify its quality and its movement to streams and oceans, and affect geomorphic processes. The hydrologic and physical environments in turn have a marked influence on the distribution and behavior of plants. Unraveling these complex interrelations will provide a better understanding of man's environment and the processes that affect it. The role of plants as consumers of water is discussed under "Soil Moisture and Evapotranspiration," and of aquatic plants in hydrology, under "Limnology."

Relation between tree form and disposition of precipitation

A randomly stratified sampling experiment is being conducted by M. R. Collings and R. M. Myrick to determine rainfall interception in a juniper (*Juniperus osteosperma*) and pinyon (*Pinus edulis*) woodland at Cibecue Ridge, Ariz. Using the Latin square and three-way analysis of variance as statistical techniques, the direction of the gage under the tree, distance of the gage from the center of the tree, tree species, size of the tree, size of the storm, and respective interactions were tested at the 5-percent level for significance. Their findings indicate that the compass direction of the gage from the tree trunk is highly significant, while species of juniper and pinyon is not significant. A single precipitation versus interception regression may be used for both juniper and pinyon. Scrub oak (*Quercus turbinella*) and tree oak (*Q. arizonica*) intercept more rainfall than do juniper and pinyon trees. In vegetation-modification studies on Cibecue Ridge, Collings and Myrick found that the percent of stemflow from juniper (*Juniperus osteosperma*) and pinyon (*Pinus edulis*) trees is inversely related to tree diameter.

Relation of plants to soil-moisture storage

An investigation by F. A. Branson, R. F. Miller, I. S. McQueen, R. S. Aro, and K. W. Ratzlaff of seven contiguous plant communities on soils derived from Bearpaw Shale in northeastern Montana revealed that differences in quantities of moisture stored and used from the different soils were related to differences of kinds and quantities of plants present. The study site is a west-facing hillslope on which the soils differ in texture, chemical composition, and degree of weathering. Plant species which characterize the communities exhibit a variety of adaptations to soil conditions. These include halophytic Nuttall saltbush, xerophytic big sagebrush, and gypsophytic wild buckwheat. Plant sampling at 2-inch intervals by the all-contacts point quadrat method across the contiguous plant communities (1,150 feet) supports the classical concept that plant communities are discrete entities.

Relation of tree species to geology and hydrology

Preliminary results of mapping vegetation near Washington, D.C., by R. S. Sigafoos, show that certain trees have a restricted distribution related to geology and hydrology. Some species, such as black oak, scarlet oak, and mockernut hickory, predominate in areas underlain by a schistose granitic-appearing gneiss. Other species, namely, southern red oak, post oak, and mountain laurel, are common on sites underlain by Wissahickon Formation but are not present on comparable sites underlain by the gneiss. Even on the flood plain of the Potomac River, where the predominant environmental influence on plants is flooding and sedimentation, certain species are limited to certain reaches. Shumard oak grows only in deep, fine-grained alluvium upstream from the tidal estuary. Shagbark hickory, which is common on flood plains and low terraces in Pennsylvania and on upland sites in the Appalachian Mountains in Virginia, is exceedingly rare along the Potomac River.

Size and abundance of trees affected by flooding

Quantitative studies of vegetation along a 2-mile reach of the Potomac River by R. S. Sigafoos show a high correlation between the mean size of trees and flooding. The mean basal area (cross-sectional area of the trunks) of trees not damaged by the 1948 ice jam is significantly larger than that of trees damaged by the ice and of trees that are frequently flooded. Although the mean basal area of trees that were damaged by the ice, but flooded only once in 2 years on the average, is larger than that of trees flooded more frequently, the difference is not significant.

Statistical studies of vegetation mapping

The percentage of sites at which a species grows (frequency) was found by J. C. Goodlett, in studies of low flow of streams in Georgia, to be related to the percent maximum basal area for that species within the region. High correlation coefficients between frequency and percent maximum basal area for tree species were computed also by R. S. Sigafoos in his quantitative studies along the Potomac River. Similar high correlations were found between the percent basal area and the percent number of stems in a plot for several tree species. Approximately 75 percent of the differences in basal area of some species is the result of differences in frequency, suggesting that mapping of vegetation based on the presence or absence of species is valid and contains a measurable error.

Historic changes in vegetation patterns in the Southwest

Channel area along one 5-mile reach of the Gila River in central Arizona has decreased by a factor of about nine since 1914. R. M. Turner has found that during the same period batamote (*Baccharis glutinosa*) has virtually disappeared from the area; it is no longer dominant at any site and occurs mainly as a narrow fringe along the edge of the channel. Seed weed (*Suaeda torreyana*) has declined by a factor of about two. The areas formerly occupied by these declining species and the areas abandoned by the channel are now covered by a dense growth of saltcedar (*Tamarix pentandra*), a species that apparently invaded the region after 1914.

Changes in vegetation and erosion in the arid Southwest in the past 80 years are attributed by J. R. Hastings, Institute of Atmospheric Physics, University of Arizona, and R. M. Turner to be due primarily to change in climate. Historical, biological, and photographic studies show that the distributional ranges of certain species below 5,000 feet altitude are higher in elevation than formerly. The abundance of some species, notably mesquite, has increased near the center of their altitudinal range. Overgrazing by cattle is believed to be of secondary importance in explaining the changes, and fire suppression and increased jackrabbit·density are considered to be insignificant factors.

Growth rates of trees related to hydrologic and climatic variables

Radial growth studies of trees by R. L. Phipps have shown that in discontinuous tree rings, areas of growth are arranged spirally around the trunk, and that the degree of spiralling differs both between rings and vertically within any given ring. Patterns of discontinuous or "missing" rings at various vertical levels within a tree may be correlated with certain hydrologic variables on a subseasonal basis. Vertical distribution of ring volume, even in species that do not exhibit discontinuous rings, may also be correlated with variations in certain hydrologic parameters. Preliminary analysis of data from a rich deciduous forest of southeastern Ohio suggests that ring volume of any given tree may be correlated with only certain ranges of environmental variables, and that the correlative range may vary from tree to tree.

Correlation of ring widths, as measured on radial increment cores of coniferous trees, with annual precipitation has been shown by W. J. Schneider and W. J. Conover (p. B185–B188) to be of little value in inferring past precipitation in central New York. The two variables, however, are not completely independent.

GLACIOLOGY

Traditionally, glacial deposits in the geologic record have been used as prima facie evidence of paleoclimates. Recent theoretical and field investigations, however, suggest that the quantitative relation between glaciers and climate is complex, and that simple generalizations are often incorrect. In order to better understand the meaning of glacier variations in terms of climatic events, studies are underway on the climatic influences on existing glaciers (expressed as the mass budget), the dynamics of flow of these glaciers, their recent variations in length and thickness, and glacier variations of the recent past.

Mass budget studies of South Cascade Glacier

Recent studies of the net mass budget of South Cascade Glacier, Wash., by M. F. Meier and W. V. Tangborn demonstrate that the net budget shows little relation to the traditionally used parameters of climate. Mean annual temperatures and precipitation for the budget (or hydrologic) years 1962 and 1963 were almost identical, but South Cascade Glacier showed a slightly positive net budget (+0.5 feet of water equivalent averaged over the glacier surface) in 1962, and a strongly negative net budget (−4.3 feet) in 1963. The difference was due to consistent differences in freezing-level altitudes during times of winter precipitation, and a period of high energy income in the fall of 1963. The two effects combined to produce marked differences in the persistency of low-albedo conditions in the two summer melt seasons. Thus it appears that glacier growth and decline is not related in any obvious way to winter precipitation and summer temperature, nor is it related to mean annual precipitation and temperature.

Studies of glacier flow at Blue and Nisqually Glaciers

An International Geophysical Year project on the flow of the lower Blue Glacier, Wash., by a team under the direction of R. P. Sharp, California Institute of Technology, has been continued in order to collect data averaged over several years. M. F. Meier, of the U.S. Geological Survey, a member of that team, has completed an analysis of the surface velocity and strain-rate data. This analysis clearly shows the effect of the valley walls and the curving channel on the flow pattern. Components of velocity normal to the surface relate to the net mass budget and the rate of glacier thickening or thinning. Orientations and magnitudes of the components of the strain-rate tensor agree with theoretical expectations arising from the net mass budget, the changing surface slope, and the curving flow. Analysis of a hypothetical stream sheet, of narrow width but extending from the surface of the glacier to the bed, yielded fresh insight into several problems regarding subglacial slip, englacial flow, and the general applicability of empirical flow laws.

A large amount of data, spanning several decades, collected by Arthur Johnson and G. C. Giles on Nisqually Glacier, Wash., is being analysed by M. F. Meier and J. N. Johnson to determine the mode of flow of this interesting glacier, and to answer several pressing questions about the theory of glacier flow. One of these questions concerns the relation of ice velocity at a given cross section to the surface slope and the ice thickness. The Nisqually results indicate that a single-valued functional relation does exist, but that it is not the power-law relation expected from the simple analysis used in all existing theories of glacier flow. Another pressing question concerns the velocity of slip on the bed. Indirect calculations suggest that the slip velocity is not a single-valued function of the shear stress, at least not when the shear stress is calculated by conventional formulae.

Recent glacier variations

Comparison of mapping of Teton Glacier, Wyo., in 1963 by J. C. Reed, Jr., (p. C147–C151) with earlier maps, ground photographs, and a map constructed from aerial photographs taken in 1954 indicates that the rate of retreat of the terminus has diminished, and that the thickness of the upper part of the glacier has increased since 1954. These observations suggest that the terminus of the glacier may begin to advance within the next few years.

Studies of the maximum ages of the first trees to grow on modern moraines on Mt. Rainier, Wash., by R. S. Sigafoos, E. L. Hendricks, and D. R. Crandell (D. R. Crandell and R. D. Miller, chapter D) indicate that these glaciers have been active since early in the 13th century Many glaciers have receded from a maximum advance in the last 125 years; others reached maximum extents at times ranging to as early as the middle 14th century. These advances began after deposition of an ash layer from Mt. St. Helens between 3,000 and 3,500 years ago. Presence of an ash layer more than 8,800 years old in areas just beyond the 13th- to 19th-century moraines indicates that the glaciers of Mt. Rainier were larger during the last 700 years than at any time since the end of the Wisconsin Glaciation, according to Crandell.

Ages of a few trees growing in Little Ice Age cirques in the Sierra Nevada, Calif., were found by R. S. Sigafoos and R. J. Janda to be more than 300 years. This suggests that ice has not been in the cirques for at least that length of time, and that recent glacial activity in California was not contemporaneous with that on Mt. Rainier.

PERMAFROST

Studies of permanently frozen ground in Alaska centered around ground-water conditions below the permafrost zone and on thermal characteristics of the soil in and above the permafrost zone.

Preliminary analysis of data gathered in the Copper River Basin, Alaska, since 1955 shows that permafrost in this area is in equilibrium or is aggrading under present climatic conditions. This trend is in line with observations from many other Arctic areas.

T. L. Péwé (1–64), continuing his study on the distribution of ice wedges in Alaska, has classified ice wedges into three categories (active, inactive, fossil) which reflect their degree of present growth. The classification has been related to the climatic conditions of an area in which a specific category of ice wedges occurs, and it was observed that growing ice wedges are confined to areas with a mean annual air temperature of −6° to −8°C. or colder.

J. R. Williams has completed a report (1–63) on the relation of permafrost to the occurrence of ground water, based on a 4-year study of published reports and on unpublished data relating to subsurface conditions. He notes that permafrost forms an impermeable barrier to recharge, discharge, and lateral circulation of ground water in Alaska north of the mountains along the Pacific Coast. Its greatest effect on ground water is in the area draining to the Arctic Ocean, where permafrost is present nearly everywhere to depths ranging from 500 to 1,330 feet. In this area, ground water in bedrock beneath permafrost in the foothills of the Brooks Range and the Arctic coastal plain is brackish or saline. In the Brooks Range, however, potable water is discharged from springs along faults cutting limestone of the Lisburne Group.

Unfrozen zones in alluvium beneath large rivers are potential sources of large supplies of ground water. Even though the alluvium beneath small streams may be perennially frozen, it is possible to develop a year-round aquifer in the alluvium by thawing the permafrost and by retarding the penetration of seasonal frost. Methods of developing a shallow alluvial aquifer beneath Selin Creek near Cape Lisburne include stripping the vegetation and upper few feet of alluvium, circulating water warmed in a reservoir through the alluvium by pumping infiltration galleries downstream, and erecting snow fences to retard penetration of winter frost.

In the area between the Brooks Range and the Pacific coast ranges, even though permafrost is as much as 600 feet thick, it is broken by unfrozen zones through which ground water can circulate and be recharged and discharged. Ground water is readily available in alluvial deposits of flood plains, low terraces, and alluvial fans, and to a lesser extent in glacial deposits, beaches, and bedrock. Salinity of the water is a problem in coastal plains and in the Copper River lowland. Permafrost in this region is generally less important than the geologic factors which affect the occurrence of water.

Studies of the water well drilled in the Kuskokwim delta near Bethel, Alaska, which obtained potable water beneath 603 feet of permafrost, were continued by A. J. Feulner and R. G. Schupp (chapter D). This is the greatest thickness of permafrost known to be penetrated by a producing water well in Alaska. At the time of temperature determinations the water averaged −0.1°C. within the disturbed portion of permafrost and 0.7°C. in the water-bearing zone beneath permafrost. Similarity of this water to that from the Kuskokwim River suggests that at least part of the recharge may come from the river. A fragment of wood presumed to have come from just below the base of permafrost at a depth of 603 feet has been dated as older than 34,000 years by the C^{14} method.

LABORATORY AND FIELD METHODS

ANALYTICAL CHEMISTRY

Manual of systematic analysis of silicate rocks

L. C. Peck (1–64) has prepared a manual that presents complete directions for systematic analysis of silicate rocks and minerals by conventional methods. Many refinements of the classical methods of rock analysis and solutions of special problems have been included, based on 20 years of experience in making precise analyses on a production-line basis. Particular emphasis has been given to illustrations and descriptions of special equipment. These should aid those chemists who are involved in establishing a similar operation in this specialized field.

Clay membrane electrodes

Clay minerals such as montmorillonite and illite can be compacted with pressure into cation-sensitive membrane electrodes which are analogous electrochemically to glass electrodes. Details for the construction of a clay compaction press and the use of clay membrane electrodes in ion-exchange studies were presented by B. B. Hanshaw. The electrical potential developed between a clay membrane electrode and a reference electrode in contact with certain solutions of monovalent and divalent ions is given by an adaptation of the Nernst equation. From measurements of the electrical potential, the free energy of reactions or exchange constants for a series of reactions between various cation species were obtained. These determinations indicate that compacted clays prefer monovalent over divalent cations.

An arsenazo-III method for trace amounts of thorium

A new spectrophotometric reagent for thorium, arsenazo-III, developed by the Russian chemist, S. B. Savvin, was applied by Lillie Jenkins and Irving May to determine thorium in rocks and minerals in the parts-per-million range. They have modified the method by the addition of separations to take care of interferences by zirconium, titanium, niobium, calcium and the rare-earth elements. Employing arsenazo-III instead of the conventional reagent, thoron, increases sensitivity 5 to 6 fold and at the same time cuts analysis time by half. The increased sensitivity enables the analyis of smaller samples than was possible previously. Results on 37 determinations on granite, sample G–1, average 52 parts per million, the same value as for the conventional thoron method; 14 determinations on diabase, sample W–1, average 2.6 ppm, compared to 2.4 ppm by thoron.

Use of the statistic chi-squared in evaluating analyses

F. J. Flanagan (p. C157–C158) suggests the use of χ^2 for evaluating objectively the results of a chemical analysis if there is available a well-analyzed sample like G–1 whose population means and standard deviations are known. The differences between the analyst's values and the means of the analyzed sample are divided by the standard deviation to form standardized normal deviates. The sums of the squares of these deviates follow the χ^2 distribution. This enables one to use published tables of χ^2 at a specified probability for the objective evaluation. The technique is useful in any field for which the data on a well-analyzed standard are available.

Determination of fluorine in silicate rocks

Fluorine determinations on silicate rocks, once rarities, are now routine. To meet increased demands, L. C. Peck and V. C. Smith have developed a faster and more accurate spectrophotometric method. Difficulties with previous methods based on fluoride bleaching of thorium or zirconium lakes, such as instability of the lakes and the necessity for close control of pH, were eliminated by using a water-soluble chelate system, Zr-SPADNS, at an acidity high enough for the system to be insensitive to appreciable changes in acid concentration. The sample is sintered with a flux consisting of Na_2CO_3, ZnO, and $MgCO_3$. After leaching the melt and filtering to remove the alumina and silica retained in the insoluble, fluorine is separated from the filtrate by distillation from sulfuric acid solution at 135°C. The Zr-SPADNS reagent is then added to an aliquot of the distillate to prepare the color system for spectrophotometric measurement. The range of concentration covered is from 0.005 to 2.0 percent fluorine.

Oxygen sheath for flame photometry

An oxygen-sheathed burner for flame photometry produces a hotter and more stable flame than does the normal burner, resulting in increased sensitivity and higher precision for some elements. Irving May, J. I. Dinnin, and Fred Rosenbaum (p. C152–C153) have constructed and tested an oxygen sheath for the atomizer-burner of the Beckman flame photometer. This unit is simpler, more convenient, and very much less expensive than the sheath which is currently available commercially. Of the elements tested (K, Li, Rb, Cs, Mg, Ca, Ba, and Mn), increased sensitivity by factors of 2 to 5 were obtained for Ca, Li, Mn, and Ba.

Pierre Shale analyses

L. F. Rader and associates have completed an analytical study of 151 samples of Pierre Shale submitted by H. A. Tourtelot. The average content of various elements determined is as follows: Total carbon is 1.17 percent (consisting of mineral carbon, 0.42 percent, and organic carbon, 0.68 percent). Trace metals, in parts per million, are: V, 114; Cu, 22; Zn, 81; Pb, 24; As, 8; Mo, 2; and Se, 0.8.

Sulfur content of samples G–1 and W–1

I. C. Frost and J. A. Thomas determined total sulfur in granite, sample G–1, and diabase, sample W–1, using the Leco high-temperature induction furnace and automatic titration method. The average of 17 runs on 3 different bottles of G–1 is 74 parts per million S, with a median value of 78 ppm S. For W–1 the average for 15 runs on 3 different bottles of sample is 124 ppm S, with a median value of 130 ppm S. The value for G–1 agrees with that reported by Ricke but that for W–1 is almost 100 ppm less than his value.

Microdetermination of platinum metals and gold

A combination of conventional fire assay, ion exchange, and emission spectrographic techniques was developed by Dwight Skinner, P. R. Barnett, Claude Huffman, and L. B. Riley for the separation, concentration, and quantitative determination of micro amounts of platinum, palladium, rhodium, and gold in rocks and mineralized samples. The silver bead produced by a conventional fire assay is dissolved, and its content of precious metals collected onto an anion-exchange resin. A small amount of silica is added to the resin and the mixture is ignited. The resulting siliceous residue is then spectrographed. Routine limits of detection are 0.001 ounces per ton (0.03 parts per million) for Pt, Au, and Rh, and of 0.0003 oz per ton (0.001 ppm) for Pd. Replicate analyses of an oxidized copper ore and a chromite-dunite ore indicate acceptable reproducibility.

Semimicro procedure for ferrous iron

The detailed procedure of a semimicrovolumetric method for determining ferrous iron in nonrefractory minerals was published by Robert Meyrowitz.[93] The sample (25–100 milligrams) is decomposed by heating with hydrofluoric and sulfuric acids, and the decomposition mixture is added to excess standard potassium dichromate. The excess dichromate is titrated with standard ferrous ammonium sulfate in the presence of phosphoric acid, using sodium diphenylaminesulfonate as indicator. Determinations of the FeO content of various silicate minerals by this semimicroprocedure are in satisfactory agreement with those by standard macroprocedures.

Ion-exchange separation of tin from silicate rocks

Claude Huffman, Jr., and A. J. Bartel (chapter D) have developed an ion-exchange separation of microgram amounts of tin from silicate rocks, which reduces the separating time by a factor of about four as compared to the familiar hydrobromic-hydrochloric acid distillation procedure. Tin is absorbed on an oxalate-form, anion-exchange resin from a hydrochloric-oxalic acid solution and is eluted with 1*M* H_2SO_4. The tin in the eluted solution is concentrated by a carbonate-chloroform extraction and oxidized to bring it into water solution by wet-ashing with HNO_3, H_2SO_4, and $HClO_4$. The tin is then determined fluorimetrically with flavanol. Using a 2-gram sample, the lower limit of detection of tin is about 2 parts per million.

Microdetermination of magnesium

Robert Meyrowitz (1–64) completed work on the direct spectrophotometric microdetermination of large amounts of magnesium with Clayton yellow, in small samples of silicate minerals. The precision of duplicate determinations is about 3 percent of the amount present, about the same as that given by other microprocedures. The common rock-forming elements do not interfere. It is feasible to determine, without separations, as little as 0.5 percent MgO on 2 milligrams of sample.

High-temperature and high-pressure decomposition of refractory minerals

High-temperature, high-pressure acid decomposition of refractory minerals is of particular value for determining alkali elements and for decomposition in non-

[93] Robert Meyrowitz, 1963, A semimicroprocedure for the determination of ferrous iron in nonrefractory silicate minerals: Am. Mineralogist, v. 48, nos. 3–4, p. 340–347.

oxidizing atmospheres, as in determining ferrous iron. The efficiency of high-temperature attack of refractory minerals with hydrofluoric acid has been studied by others using teflon-lined bombs. Irving May, J. J. Rowe, and J. F. Abell designed a platinum-lined Morey bomb which was built by R. E. Letner. The bomb has a removable nichrome-cased 3½-milliliter platinum crucible and has been used with no failures of the seals at temperatures up to 450°C and pressures estimated at 6,000 pounds per square inch. Complete decomposition by hydrofluoric acid was obtained with garnet, beryl, chrysoberyl, phenacite, sapphirine, and kyanite. Samples with a high aluminum content formed difficultly soluble aluminum fluoride precipitates. Studies are being made on determining silica spectrophotometrically after a hydrofluoric acid decomposition in the bomb.

Analysis of new or unusual minerals

R. E. Stevens, in collaboration with R. J. P. Lyons, Stanford Research Institute, deduced from infrared absorption spectra that some beryl contains hydroxyl groups, contrary to previous understanding. Hydroxy end members comprise less than 10 percent of the composition of 12 beryl samples analyzed by Stevens. Inclusion of the hydroxy end members in the formulation accounts completely for the composition of the analyzed beryls.

A microchemical analysis of a new vanadium garnet with the unusually high vanadium content of 18.3 percent V_2O_3 was made by Robert Meyrowitz. A new hydrated copper-iron arsenate from Majuba Hill, Nev., was also analyzed by Meyrowitz.

Unusual minerals analyzed by B. L. Ingram include: a new rare-earth carbonate, mckelveyite; a rare-earth calcium titano-silicate; a new uranium arsenate; and a leucophosphite from Brazil with a low potassium content (0.75 percent K_2O) and a high ammonium content (2.4 percent $(NH_4)_2O$).

An interesting chromite was analyzed chemically by J. I. Dinnin. A summation of less than 100 percent was first obtained, indicating the presence of some element not looked for. H. W. Worthing found more than 5 percent zinc spectrographically, and this was corroborated by quantitative X-ray fluorescence analysis by H. J. Rose, Jr.

Four samples of the new mineral, mcallisterite, $2MgO \cdot 6B_2O_3 \cdot 15H_2O$, from Furnace Creek, Calif. were analyzed by Angeline Vlisidis.

Posnjakite, a new basic copper sulfate, $Cu_4SO_4(OH)_6 \cdot H_2O$, was analyzed by Laura Reichen. Also analyzed by her was a hydrous magnesium borate, preobrazhonskite, from the Inder Deposit, U.S.S.R.

A semimicroanalysis by Robert Meyrowitz, in collaboration with Mary Mrose, established the composition of the mineral kolbeckite to be $ScPO_4 \cdot 2H_2O$. Kolbeckite was originally reported by others to be a hydrated silicate-phosphate of aluminum, beryllium, and calcium. Mrose thought the major cation to be scandium instead of aluminum. By experimentally testing the 8-quinolinol procedure used by the original authors, Meyrowitz also proved that if one were not aware of the presence of scandium, its behavior in the analysis would lead this element to be reported as aluminum and beryllium in the same ratio as originally postulated.

OPTICAL SPECTROSCOPY

Determination of rare-earth elements

In a study of allanites from Mt. Wheeler, Nev., by D. E. Lee and Harry Bastron, rare-earth analyses give supporting evidence that a satisfactory complete analysis can be made with spectrographic methods. Some interesting rare-earth data were obtained on the allanites, pointing to an astonishingly complex history of fractional crystallization. That fractional precipitation plays a dominant role in determining the concentration of the rare-earth elements was suggested by Murata and others,[94] [95] who proposed as a numerical index of the stage of fractionation, sigma, the quantity (La+Ce+Pa) expressed in atomic percent of total rare-earth elements. In samples from various localities they found sigma to range from 58 to 87 in monazite (26 samples), 61 to 87 in allanite (3 samples), 63 to 82 in cerite (3 samples), and 81 to 95 in bastnaesite (8 samples). The range of 62 to 81 for sigma, found by Bastron, for allanites from Mt. Wheeler shows an extremely wide variation in the extent of fractionation for a single location. The highest sigma values were obtained where limestone instead of quartzite is the country rock.

Determination of lithium by direct-reading spectroscopy

The direct-reading spectrometer was used by Sol Berman to determine lithium in biotite, feldspar, hornblende, plagioclase, and quartz. The Li 6707.84A line was the only one strong enough to record directly in the

[94] K. J. Murata, H. J. Rose, Jr., and M. K. Carron, 1953, Systematic variation of rare earths in monzonite: Geochem. et Cosmochim. Acta, v. 4, p. 292–300.

[95] K. J. Murata, H. J. Rose, Jr., M. K. Carron, and J. J. Glass, 1957, Systematic variation of rare-earth elements in cerium-earth minerals: Geochem. et Cosmochin. Acta, v. 11, p. 141–161.

concentration range required. The strong reversal of this line with increasing lithium concentration, which has always been a problem with photographic methods, is also a special problem for direct reading. Such reversal is easily recognized on a plate and is corrected for by resorting to a line-width measurement rather than a line-blackness measurement. For direct-reading analysis with the customary 0.1-mm exit-slit width set dead center on the line, there is at first an increase in integrated line intensity and then a decrease as the concentration of lithium increases. Thus the same value of integrated-line intensity can be obtained from two very different lithium concentrations. By replacing the exit slit with one that is much wider, 1 mm, the entire broadened line can be measured. With an IP28 photomultiplier tube used as the detector, an analytical curve was obtained having integrated values continuously increasing from 0.0001 to 2 percent lithium. The slope between 0.02 and 0.4 percent is poor, but it is close to unity above 0.4 and below 0.02. Lithium can be determined with excellent precision between 0.0001 and 0.02 percent with assurance that a sample high in lithium content will not be misinterpreted as one in the low range.

X-RAY FLUORESCENCE ANALYSIS

Determination of major elements

H. J. Rose and Frank Cuttitta continued the development in Washington, D.C., of combined X-ray-fluorescence–chemical methods for the total analysis of rocks and minerals. Two objectives have been stressed in the X-ray fluorescence work—determinations that are time consuming or unusually difficult to perform by chemical methods, and determinations to be made on samples limited to semimicro size. To date, columbite, tantalite, allanite, epidote, microlite, rutile, ilmenite, magnetite, sphene, amphibole, mica, and tektites have been analyzed successfully with sample sizes of 25 to 50 milligrams. In a special application, 21 sulfides were completely analyzed for the elements Cu, Ag, Fe, Sb, As, and S on only 15-mg samples.

A similar X-ray fluorescence laboratory has also been set up in Menlo Park, Calif., by W. W. Brannock, who with Al Bettiga and Leoniece Beatty, have analyzed olivine, garnet, amphibole, pyroxene, pumpellyite, and omphacite.

Determination of Rb/Sr ratios

A simple method for determining Rb/Sr ratios useful for guiding geochronologists in the selection of samples likely to yield meaningful data for age calculations was developed by H. J. Rose. Determinations can be made in approximately a 3-minute scan of the ground materials. No effort is made to control particle size, and a simple measurement of peak heights is all that is required. The X-ray method seems potentially useful down to at least 10 parts per million, and with refinements, perhaps to 1 ppm. Comparison of X-ray determinations with those of the isotope-dilution technique shows surprisingly good agreement, as indicated below, when the simplicity of the X-ray method is considered.

	Rb/Sr, *by X-ray technique*	Rb/Sr, *by isotope-dilution technique*
Shale	0.8	0.76
Do	.5	.65
Graywacke	.3	.22
Do	.17	.14
Slate	.10	.08
Do	5.6	6.0

Determination of Cl, Br, and I

Because of similarities in chemical properties, Cl, Br, and I are very difficult to determine chemically in a sample containing all three elements, especially if the available sample is small. H. J. Rose had devised a simple X-ray fluorescence method that allows determination of as little as 0.05 percent of each element in a single 10-milligram sample. Samples and standards are ground to a fine powder and spread as thin layers on scotch tape before X-ray excitation. Excluding the time required for the preparation of standards, the 3 halogens were determined in 6 tourmaline samples in about 30 minutes. Several weeks would have been required to make these analyses by chemical methods.

Routine rock analysis for major elements

With the establishment by Isadore Adler, H. J. Rose, and Francis Flanagan of the basic X-ray fluorescence method for determining major elements in rocks and with the acquisition of a 10-channel X-ray quantometer, X-ray methods have largely replaced or supplemented wet methods for rapid rock analysis. Experience indicates that about 350 determinations per man per week are realized by the X-ray method, compared to about 100 determinations per man per week by "rapid" chemical means. Na, $H_2O^{\pm}$, CO_2, and state of oxidation of iron must still be determined by wet chemical methods at present.

By substituting cerium oxide for lanthanum oxide as a heavy absorber, Leonard Shapiro has modified the preparation of pellets for X-ray fluorescence analysis so that magnesium can be determined with better accuracy than was previously possible. The lower solubility of cerium oxide in the lithium borate melt requires that the melt be ground and remelted. The extra fusion step results in a more uniform powder than with a single fusion and is well suited to routine handling, as less care is required for a satisfactory pellet. Several other improvements in the method were made in the course of adapting the procedure to the quantometer. An attachment was added to convert automatically the chart intensities to printed concentrations. A recycle timer was also added to allow the quantometer to repeat its integration cycle and print the results as often as desired according to a pre-set schedule. New detectors were installed to replace gas-flow types previously used, without sacrificing sensitivity or stability. The manner in which a powdered sample is spread on a bed of boric acid prior to pelletization influences the results, and this source of variation was minimized by a simple sample spreader designed by Shapiro. A 50-milligram sample in ½ gram of fusion mixture can now be spread uniformly to yield satisfactory replicate analyses.

ELECTRON MICROPROBE STUDIES

Pyrrhotite-sphalerite phase studies

The application of the electron microprobe by Isadore Adler to analytical problems in phase studies by P. B. Barton (Adler and Barton, 1–64) has aided in making a nearly complete extraction of useful information from earlier pyrrhotite-sphalerite runs in the Fe-Zn-S system for temperatures between 580°C and 850°C. The microprobe performance has exceeded expectations to the extent that the results are considered equal to, or better than, X-ray diffraction for determining the FeS content of sphalerite. The microprobe precision is about 2 percent of the absolute Fe content (but no runs less than 10 percent FeS have been evaluated). There is good agreement between the X-ray and microprobe results up to 30 percent FeS. Because of third-dimensional uncertainties in samples with higher FeS content it is often necessary to measure 10 or more grains in each section to rule out unwarranted values.

Mineral analysis

Cynthia Mead analyzed three minerals for Mary Mrose: gerstleyite from the Kramer borate deposit, Kern County, Calif., a pulszkyite-like mineral from Salida, Colo., and a yellow-green monoclinic mineral from Majuba Hill, Nev. Probe analysis showed the gerstleyite to contain more than 50 percent Sb, major S, and a small amount of Ag; the pulszkyrite, major Zn and Cu, and probably a small amount of S; and the yellow-green mineral, Fe, Cu, and As. The latter also contained numerous angular inclusions of quartz. A strontium-bearing barite from Richelsdorf, Germay, contained 11 percent SrO.

A preliminary electronprobe analysis by Cynthia Mead of a possible new strontium-niobium mineral was reported. The sample, a small veinlet in a pyrochlore crystal from the Museum zone, Mbeya carbonatite, Tanganyika, is characterized by a higher reflectivity and a lower polishing hardness than the adjacent pyrochlore. It has a locally zoned texture and is nearly colorless. Its powder pattern does not match any known mineral. Quantitative electronprobe analysis indicated 52 percent Nb and 14 percent Sr.

Mineralization of blood vessels

Some very interesting work has been carried on by A. J. Tousimis, of George Washington University, using the Geological Survey electronprobe and some of the experimental facilities at the Walter Reed Institute of Research. Among other things, Tousimis has been studying the hardening and mineralization of blood vessels. Examination of electron-opaque deposits found in the elastica of the vessel walls revealed a periodic deposition of both calcium and phosphorus within the vessel wall and specifically in the elastica. Quantitative electronprobe analysis revealed a Ca/P weight ratio of 2.18 within the mineralized portion of the blood vessel, suggesting the presence of apatite. This was confirmed by X-ray and electron diffraction. Hydroxyapatite was also found in the experimentally mineralized rat aorta, in a malignant tumor of the human eye (retino-blastoma), and in bones of a normally growing guinea pig.

PETROGRAPHIC TECHNIQUES

Hexanol as a wetting agent in mineral separations

Theodore Botinelly has developed a useful technique, using hexanol for separating some sulfides and native metals from admixed silicates with comparable densities. Apparently the sulfides are wetted by hexanol and other alcohols, whereas the silicates are not. The higher alcohols are immiscible with, and lighter than water. A 1 to 9 mixture of hexonol and water is vigorously shaken with the silicate-sulfide mixture. Hexanol coats and wets the sulfide grains, giving a composite body which has a density less than water and which then floats to the hexanol-water interface. The method requires further development for general use but has already been successfully employed on many common sulfides and on native copper and iron.

Use of centrifuge in heavy-liquid separations

Robert Schoen and D. E. Lee (p. B154–B157) have developed a laboratory procedure whereby routine separations of mineral particles as small as 10 microns are possible. The method, which is applicable to fine-grained igneous rocks, hydrothermally altered rocks, and sedimentary rocks not ammenable to treatment by normal separation methods, depends on the centrifuging of fine fractions in heavy liquids. The flocculation which normally hinders or prevents satisfactory sink-float methods of mineral separation in fine-grained materials is avoided by very rapid application of centrifugal force before flocculation occurs.

Inexpensive fruit dye used to stain plagioclase

R. V. Laniz, R. E. Stevens, and M. B. Norman (p. B152–B153) have successfully developed new procedures for sequentially staining K-feldspar yellow with cobaltinitrite, and plagioclase red with the inexpensive fruit dye F. D. and C. No. 2 (amaranth). The method is applicable to rock slabs, thin sections, and mounted sand grains. Although the amaranth strain is not specific for plagioclase it may be used conveniently, as other minerals can be distinguished by the hue and depth of the stain. The new staining technique has a distinct advantage over the potassium rhodizonate method in that the fruit dye is inexpensive and can be obtained from many dyestuff distributors.

GEOCHEMICAL AND GEOBOTANICAL EXPLORATION

Mercury detector developed

Instrumentation has been developed by W. W. Vaughn and J. H. McCarthy, Jr., (chapter D) for the determination of submicrogram amounts of mercury in rocks, soils, and gas. The technique is based on the principle of atomic absorption spectroscopy. An analog signal, produced by absorption of ultraviolet light by mercury vapor, is converted to digital form, resulting in a very sensitive and reliable means of measuring mercury vapor. Although the method is very simple in theory, elimination of interfering substances such as particulate matter and organic gases that also absorb ultraviolet light has been a difficult problem. In practice, mercury is volatilized by heating a rock or soil sample, and the mercury vapor separated from interfering constituents by selective absorption on gold. Heating of the gold releases the absorbed mercury, which then passes through the sensing chamber where it is measured. About 5 nanograms (0.005 micrograms) of mercury can be reliably measured; thus 5 parts per billion of mercury can be determined using a 1-gram sample.

New method for determining mercury in vegetation

F. N. Ward and J. B. McHugh have developed a spectrophotometric technique (chapter D) for determining small amounts of mercury in vegetation. The method is based on the reaction of mercury with dithizone after sample dissolution by wet ignition under reflux. The technique is useful for determinating as little as 0.4 part per million of mercury in dry vegetation, which is sufficiently precise for biogeochemical prospecting.

Metal content of stream sediments in west-central Maine

E. V. Post has studied, by means of colorimetric and spectrographic analyses, stream sediments from 5,000 square miles of glaciated terrane in west-central Maine. The metal content of the stream sediments reflects the metal content of underlying bedrock that ranges from granite to gabbro, and from pelitic slate to metavolcanic rocks. Data obtained suggest that the southwestern part of the Katahdin granite batholith is relatively rich in metals such as Mg, Fe, Co, Cu, Zn, Ni, and V as compared to the remainder of the pluton. On the whole, samples of stream sediment collected over granites in west-central Maine are deficient in Ca, Cu, and V, and contain more than average amounts of Co, Cr, and Pb when compared with abundances of these elements in granites of the earth's crust. Similarly, sediments collected over pelitic slates of Devonian age are deficient in Ca, Mg, Co, Cu, Pb, Ni, and V, and are above average only in Cr. Sediments collected in terrane underlain by Ordovician metasedimentary and metavolcanic rocks contain about average amounts of Cu, above average amounts of Cr and Pb, and are deficient in Ca, Mg, Co, Ni, and V.

Metals in bedrock, soils, and plants in Idaho

In a geochemical prospecting investigation in southeastern Idaho, F. B. Lotspeich and E. L. Markward (1–63) studied the interrelations among the metal content of (1) bedrock (Phosphoria Formation), (2) an overlying colluvial soil of extraneous origin, and (3) vegetation growing in the soil.

Iodine content of Spanish-moss studied

Spanish-moss plants growing at varying distances from the ocean were sampled by H. T. Shacklette, and their iodine content was determined by M. E. Cuthbert. As these plants have no soil connections, they must get all their elements from the atmosphere, yet they have about the same range in iodine content as do typical soil-rooted plants in Wisconsin. This relation raises the question of just how much of the iodine content of soil-rooted plants comes from the soil and how much is obtained from the air. This matter of source of iodine is an important consideration where vegetation analysis is used to outline regions of iodine deficiencies and also in attempting to relate iodine content of bedrock to the iodine content of the soils derived therefrom.

Variations in blueberries growing over uranium deposits

Field observations made by H. T. Shacklette[96] of fruit variation on low blueberry plants (*Vaccinium uliginosum* L.) which grew over uranium (pitchblende) deposits in the Northwest Territories, Canada, suggested that whole plant populations varied greatly from the normal in fruit size and shape. The areal extent of this variation intensity was confined to the ore outcrops or suboutcrops. Comparisons with fruit morphology of this species grown in widely separated arctic and subarctic Alaskan locations showed these described fruit variations to be rare elsewhere. It was the areal intensity of the aberrant variations, not individual variations themselves, that was of the greater significance in delineating the underlying ore bodies.

Chemical analysis of tree rings dates major soil changes

Field studies by H. T. Shacklette (1–63), in the lead-zinc district of Grant County, Wis., of American elm trees flooded by mine and mill tailings showed that increased zinc and phosphorus in the wood marked the year when this flooding occurred. The date when the tailings settling basin causing the flooding was put in use was known, and portions of wood that were formed both before and after this date (as determined by tree-ring count) were sampled and analyzed chemically. Chemical analysis of tree rings may be a useful technique in dating a pronounced change in the chemical nature of the soil. In geochemical prospecting it is important to know if a soil chemical anomaly is caused by a naturally occurring element concentration or by man-made soil contamination; if the date of this increase in element content can be fixed, it may be possible to determine the source.

Use of citrate-soluble cobalt in prospecting

F. C. Canney reports that patterns of citrate-soluble cobalt in stream sediment in Maine appear to be a useful guide in prospecting for ore deposits associated with mafic intrusive rocks.

Fern bush found to have high antimony content

A collection of 13 samples of fern bush (*Chamaebatiaria millefolium* [Torr.] Maxim.) from the Egan, White Pine, and Schell Creek Ranges, Nevada, has been analyzed for antimony and other constituents. The antimony ranges from 8 to 200 parts per million in the plant (not ash). The distribution of this and related plants, which are widespread from the Sierra Nevada to the Great Basin in the Transition zone, suggests that analyses of antimony in this plant may be useful in prospecting.

ANALYSIS OF WATER

The growing importance of pesticides and other organic compounds as water pollutants is reflected by the increased attention given to development of methods for their identification and quantitative determination.

Analysis of organic pesticides

An extremely sensitive method for determining organic pesticides developed by Garland Stratton makes possible the measurement of concentrations on the order of 1 part per billion. The pesticide materials are extracted from 5 to 10 liters of water with an equi-volume mixture of ethyl ether, petroleum ether, and benzene. After "clean up," the extracting solvents are evaporated and the residue is redissolved in 1 milliliter of acetone to make a sample concentrate. Microliter aliquots of the concentrate are then spotted on chromatographic paper, and organophosphates, chlorinated compounds, ureas, triazines, and carbamates subsequently are identified by a series of chromogenic reagents. After group identification, individual compounds within each group are determined from R_f values obtained by inverted-phase paper chromatography. Quantitative estimates are based on a comparison of the densities of spots from samples and from standard pesticide solutions. Although the method is very sensitive, the precision is inadequate for many purposes.

A multichamber apparatus for the continuous liquid-liquid extraction and concentration of pesticides, including aldrin, dieldrin, and endrin, was reported by C. H. Wayman and Lloyd Kahn. The multichamber arrangement permits evaluation of extraction efficiencies of individual components.

[96] H. T. Shacklette, 1963, Field observations of variation in *Vaccinium uliginosum* L.: The Canadian Field-Naturalist, v. 76, p. 162–167.

New effluent collector for use in gas chromatography

Certain extracted organic pollutants may be separated by gas chromatography. In collecting gas chromatographic samples, however, contamination of one component by another can occur in the effluent line and at the effluent port, particularly if several close-boiling components are involved. The substrate from the analytical column may also condense and accumulate in the effluent line. To avoid these difficulties, D. F. Goerlitz and W. L. Lamar (1–64) have designed a special effluent collector which permits isolation of pure gas chromatographic samples. The apparatus provides an individually complete assembly for the collection of each component very near the end of the analytical column. The collector is always maintained in its own heat sink. The condensing surface can readily be washed with a small amount of solvent, and a thickened glass section magnifies and pockets the sample. The collector can be completely sealed to prevent contamination by moisture during cool-down or waiting periods. The apparatus also enhances an analytical technique, developd by the authors, wherein the components are individually collected and reinjected into a different chromatographic column to obtain two characteristic retention volumes for each component.

Organic carbon

The total organic-carbon content of certain surface-water samples has been measured by Eugene Brown and Y. A. Nishioka by complete combustion of 20 microliters of the sample in a stream of oxygen and measurement with an infrared analyzer of the carbon dioxide formed.

Solid glass pH electrodes

A solid glass hydrogen-ion-sensitive electrode capable of withstanding high hydrostatic pressures has been fabricated by B. B. Hanshaw. A self-pressurizing reference electrode has also been developed. (See also "Experimental Geochemistry, Ion-Exchange Phenomena.")

HYDROLOGIC MEASUREMENTS AND INSTRUMENTATION

During the year, further adaptations of the digital water-stage recorder were made for the recording of hydrologic data other than stage data; progress was also made on adapting it to multi-parameter recording. Instrumentation for recording data at remote locations was developed. Much progress was made on improving existing equipment for better field-data collection. Digital recorders are now installed at more than 1,500 gaging stations.

Digital-punch gage applications

R. M. Myrick and M. R. Collings have adapted the Fisher-Porter digital-punch recorder for recording rainfall concurrently with stream stage on small drainage areas in Arizona. Digital-punch gages are worked in pairs from the same clock modified to furnish 1-minute punching impulses. The precipitation gage uses a 12-inch catchment funnel and 6-inch stilling well with the gear train modified to punch to the nearest 0.01 inch of rain. The streamflow recorders work from a prerated critical-depth flume equipped with a 6-inch well. E. B. Boyd has also used pairs of digital-punch recorders for concurrent recording of stream stage and rainfall on an urban runoff project in Tennessee.

H. C. Beaber reports the successful use of a pair of digital-punch gages for recording river stage at ends of a slope reach on the Nolin River, Ky. Use of digital records and the digital computer eases the task of computing discharge on the basis of river slope and river stage.

A design for a battery-operated conductivity and water-temperature digital-punch recorder has been completed by G. F. Smoot. A selected number of conductivity cells and temperature probes may be automatically sequentially switched to a servo-balanced alternating-current bridge, which, as it comes to null, also positions the digital recorder. Battery life is longer than in conventional conductivity recorders, since no current flows except immediately preceding and during the punch-out cycle.

Digital recorders and computer techniques

The techniques for automatic recording and processing of basic streamflow data using paper-tape punching devices at gaging stations and a digital computer for processing of the data have undergone important improvements in the last 3 years, according to W. L. Isherwood. These improvements have been mostly in the processing technique; the field instrumentation has undergone only minor refinement.

Translation of the paper tapes punched by digital recorders from parallel-coded form into serially coded form for acceptance by the digital computer is now done by an offline paper-tape to magnetic-tape translator rather than by a paper-tape to paper-tape translator. This allows speeding up the rate of data input to the computer by a factor of 20.

Computation of mean daily discharges is now done for each day at the time the gage-height data first enters the computer, rather than at the end of the year. Data for a given station are submitted at about 3-month intervals. At the time the initial computation of daily discharges is done, a summary of the data for each day is printed for use by the field office operating the station. This summary lists maximum, minimum, and mean gage heights, effective mean gage height, mean discharge, corrections used, and bihourly gage heights for each day. The list of bihourly gage heights, previously unavailable without considerable manual work, has been found very useful for making detailed studies of the pattern of stage changes.

Printing of tables of daily discharge on the computer for use as camera copy for publication is now fully operational.

Sediment sampling

The U.S. Atomic Energy Commission has contracted with Parametrics, Inc., to develop a nuclear device for sensing the concentration of suspended sediment in streams, and preliminary studies and some flume tests have been completed on an experimental model. B. C. Colby designed a protecting body in which Parametrics, Inc., is to mount the cadmium-109 source, a reference cell, a detector, and a preamplifying system. The remainder of the system can be installed on a bridge or streambank.

B. C. Colby designed a 200-pound U.S. P–63 suspended-sediment sampler, now in production, that will accommodate either pint or quart sample bottles and enable samples to be taken in deeper and swifter streams than can be done with the P–61 sampler.

Experimental power-hoisting equipment for depth-integrated sampling of suspended sediment was developed by J. V. Skinner, B. C. Colby, and T. F. Beckers. Uniform rates of raising and lowering sediment samplers can be maintained in the range 0.5 to 2 feet per second with 4-wheeled crane and B–3 reel. On other cranes and reels, samplers up to 100 pounds can be raised uniformly in a speed range of from 1 to 4 feet per second.

V. C. Kennedy has experimented with a freezing probe for collecting samples of unconsolidated sediments. Alcohol at −50°C to −60°C is circulated through the probe which has been inserted to the desired depth in the sediment. The thickness of the core which freezes to the probe depends on the length of time the probe is left in place and on the insulation on the alcohol-supply line.

Accuracy of current-meter measurements

Wave action has long been known to affect the registration of the Price current meter when suspended from the bow of a boat, but until the past year the errors had not been evaluated in the field. N. A. Kallio tested the Price, Ott, and Vane-type current meters at a field location where controlled amounts of periodic vertical motion similar to the motion of a boat's bow in wavy water could be applied to the meter and the affect on the registration could be measured accurately. The tests showed that the registrations of the Price, Ott, and Vane-type meters are all significantly affected by vertical motion such as is encountered during discharge measurements made from boats on windy days.

G. L. Bodhaine and John Savini recorded simultaneous velocities for 66 minutes at 10 points spaced at intervals of 10 percent of the total depth in a vertical in the measuring section on the Columbia River below Priest Rapids Dam. The mean velocity in the vertical based on the entire period was 3.28 feet per second, while the mean velocities in the vertical based on 1-minute observations ranged from 2.76 to 3.71 feet per second. Study of the variation of velocities at individual points in the vertical showed that the maximum standard deviation occurred near the streambed and decreased curvilinearly to a minimum near the surface. The mean velocity in vertical equalled the velocity at 61 percent of depth and also equalled the average of velocities taken at 26 and 80 percent of depth.

Special measurements made at 5 gaging stations on the Columbia River by John Savini, G. L. Bodhaine, and others confirm that the standard Geological Survey method of computing discharge by using the average of observations at 20 and 80 percent of depth for mean velocity is as satisfactory as computing by the more elaborate method of determining the mean velocity in the vertical graphically from a curve fitted through 10 equal-spaced observations in the vertical.

Artificial stream controls

F. A. Kirkpatrick is studying artificial steam controls to evaluate the economics and effectiveness of three principal types: precalibrated critical-depth flumes, double-sheet piling, compound weirs, and broad-crested low-rubble fills.

Glass electrode for use under high pressures

F. C. Koopman and J. L. Kunkler have developed a glass electrode and reference electrode for a deep-well chemical survey instrument called UNELAN (UNderwater ELectronic ANalyzer). Preliminary tests indicate that the electrodes are about as sensitive as conventional laboratory electrodes and will withstand pressures as high as 400 pounds per square inch for more than 28 hours without damage or change in calibration.

Computer contours permeability data

J. D. Bredehoeft (chapter D) reported preliminary results of a study of the Tensleep Sandstone in the Big Horn Basin, Wyo., in which a three-dimensional polynominal surface was fitted to the data by the method of least squares. The surface coordinates are automatically contoured on an X–Y plotter using, as input, the magnetic tape prepared by the digital computer.

Petrologic miscroscope automated to measure sand-grain orientation

R. R. Bennett and J. D. Bredehoeft have developed a petrologic microscope for automatically measuring the statistical orientation of sandstone grains. Recent studies by other investigators indicate the possibility of relating the microscopic fabric of sediments to prevailing energy conditions in the sedimentary basin at time of deposition. If the possibility materializes, a good understanding of regional changes in permeability can be achieved.

Multifunction geophysical logger

A new multifunction geophysical logger has been developed under the direction of W. S. Keys. All probes are 2 inches or less in diameter, and logs can be made to a depth of 6,000 feet. The following logs may be made simultaneously: Natural gamma and neutron-epithermal neutron or neutron-gamma or gamma-gamma; caliper and any single radiation log; fluid resistivity and temperature; and spontaneous potential and single-point resistivity. The equipment facilitates research on aquifer and fluid characteristics in cased or uncased wells.

Storm patterns measured with radar

A modified M–33 military radar unit has proven highly successful in measuring the occurrence, extent, and intensity of convective storms in Arizona. Alfonso Wilson conducted trials during the summer of 1963 in a 300-square-mile basin instrumented with rain gages at each section corner. A general correlation was found between intensity and extent of storm and thermal characteristics of the rock outcrops. Areas with rocks having high solar-induced temperatures at depth appear to have more severe thunderstorms than do surrounding areas.

D. D. Knochenmus is analyzing 16-mm movie films taken of the oscilloscope face on the U.S. Weather Bureau WSR–57 radar set to determine if the radar echoes from precipitation over a rain gage will correlate with the rain-gage catch.

Periscope for borehole inspection

F. W. Trainer and J. E. Eddy (chapter D) have developed a lightweight, portable periscope that permits observation of the rock face or condition of casing in drill holes up to 42 feet deep. With the periscope they were able to determine the number, location, and attitude of fractures and, in one hole, could observe inflow of water from a fracture above the water level. The periscope is useful also for examining inaccessible crevasses.

Cooler and humidifier for centrifuge moisture-equivalent test

I. S. McQueen and R. F. Miller (2–63) have developed and tested a low-cost, evaporative cooler-humidifier, which maintains required temperature and humidity for the centrifuge moisture-equivalent test. U.S. Patent 3,109,972 has been granted for the cooler-humidifier.

Ultrasonic agitation in sample preparation

R. P. Moston and A. I. Johnson (p. C159–C160) reported on ultrasonic agitation for disaggregating samples of sedimentary deposits preparatory to size analysis. A 15-minute agitation by ultrasonic energy appears optimum. A sample treated by ultrasonic agitation contained less silt and more clay than the identical sample treated by the standard disaggregation procedures.

Continuous water-temperature recorder

A battery-powered continuous water-temperature recorder has been developed for remote locations by using a clockwork-drive recording milliammeter, wheatstone-bridge circuitry, and thermistor-type water-temperature probes. R. L. Cory reports successful operation with weekly servicing to wind the chart drive. The equipment will operate in an air temperature range from +10°F to 140°F and record water temperatures ranging from −2°C to +40°C.

Flow-through water analyzer

J. F. Ficke has assembled and used a flow-through system for making repeated measurements of dissolved oxygen, specific conductance, pH, and alkalinity. The system incorporates a 12-volt submersible pump, 100 feet of hose, chambers for the dissolved oxygen and specific-conductance electrodes, a temperature bath for pH buffers, and taps for the withdrawal of samples. Tests have shown that the system does not modify the quality characteristics of the water flowing through it.

Automation of water-quality computations

M. D. Edwards has developed a program for the digital computer that computes daily, monthly, and annual sediment discharges for stations where stage is recorded digitally. The data input consists of sediment concentrations sampled at given times and the previously computed record of discharge based on the digital gage records.

Drag-wire probe

The drag-wire probe, originally developed by Sharp in 1962, has been improved by H. P. Guy, D. B. Simons, and J. B. Bole and is being used to study boundary-layer flows and the lift and drag on particles immersed in the flow. Velocities can be measured within 0.002 inch of a rigid boundary. Velocity profiles measured with the probe confirm theoretical concepts.

Antifouling experiment

A. L. Higer tested plates of different common metals, some of which were treated with antifouling compounds or electrical charges to determine the optimum surface or treatment for preventing growth of marine organisms on hydrologic equipment in brackish and salt waters of southern Florida. Copper plate was best among the untreated metals. The best antifouling paints provided only a short period of antifouling protection. A periodic electrical charge resulted in formation of a calcium or magnesium chloride residue which sloughed off, thereby discouraging marine organisms.

TOPOGRAPHIC SURVEYS AND MAPPING

MAPPING ACCOMPLISHMENTS

Objectives of National Topographic Mapping Program

The major function of the Topographic Division of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Map Series covering the United States and other areas under the sovereignty of the United States of America. The individual series, at various scales, constitute a fundamental part of the background information needed to inventory, develop, and manage the natural resources of the country. Other Division functions include the production of special maps and research and development in techniques and instrumentation.

In addition to the maps described below, the Topographic Division prepares shaded-relief maps, United States base maps, special maps, and also a few planimetric maps.

Procedures for obtaining copies of the maps and map products of the Survey are given in the section "How To Obtain Geological Survey Publications."

Series and scales

All topographic surveys, except those in Alaska, conform to standards of accuracy and content required for publication at the scale of 1:24,000. Initial publication scale may be either 1:24,000 or 1:62,500, depending on the need. If 1:62,500-scale maps are published initially, the 1:24,000-scale surveys, in the form of photogrammetric compilation sheets, are available as advance prints and for future publication at the larger scale. For Alaskan maps, the publication scale is 1:63,360 or "inch-to-the-mile."

Coverage of the Nation

Approximately 60 percent of the total area of the 50 States, Puerto Rico, and the Virgin Islands (fig. 8) is covered by published standard quadrangle maps at scales of 1:20,000 (Puerto Rico only), 1:24,000, 1:62,500, and 1:63,360 (Alaska only). An additional 9 percent of the total area is covered by topographic surveys, which are available as advance prints at these scales.

During fiscal 1964, 1,232 maps were published covering previously unmapped areas equivalent to 3 percent of the total area. In addition, 511 new maps at the scale of 1:24,000, equivalent to 1 percent of the total area, were published to replace 15-minute quadrangle maps (scale 1:62,500) not meeting present needs. For the extent and location of map coverage, see figure 9.

Map revision and maintenance

During fiscal 1964, about 68.0 square miles of 7½-minute mapping was added to the growing backlog of maps needing revision. Concurrently, the backlog was diminished by revising about 14,000 square miles of mapping, leaving about 372,000 square miles of 7½-minute mapping needing revision at the end of the year (fig. 10).

1:250,000-scale series

The 48 conterminous States and Hawaii are 99 percent covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service. As these maps are completed, certain changes and additions are incorporated to make them more suitable for civil use. This series of maps is being revised and maintained by the Topographic Division. Maps of Alaska at this scale are prepared and published by the Geological Survey. Coverage of the 50 States, Puerto Rico, and the Virgin Islands by 1:250,000-scale maps and the work in progress are shown on figure 11.

State maps

State maps are published at scales of 1:500,000 and 1:1,000,000, except for Alaska, which is covered by base maps published at scales of 1:1,584,000 and 1:2,500,000, and Hawaii, which is not yet covered by any of these types of maps.

Twenty-nine maps covering 33 States and the District of Columbia, compiled to modern standards, have been published in a new series comprising as many as four editions: base; base and highways; base, highways, and contours; and shaded relief on a modified base. As shown on figure 12, other conterminous States are covered by an earlier series.

Metropolitan areas

Metropolitan-area maps are prepared by combining on one or more sheets the 7½-minute quadrangles that

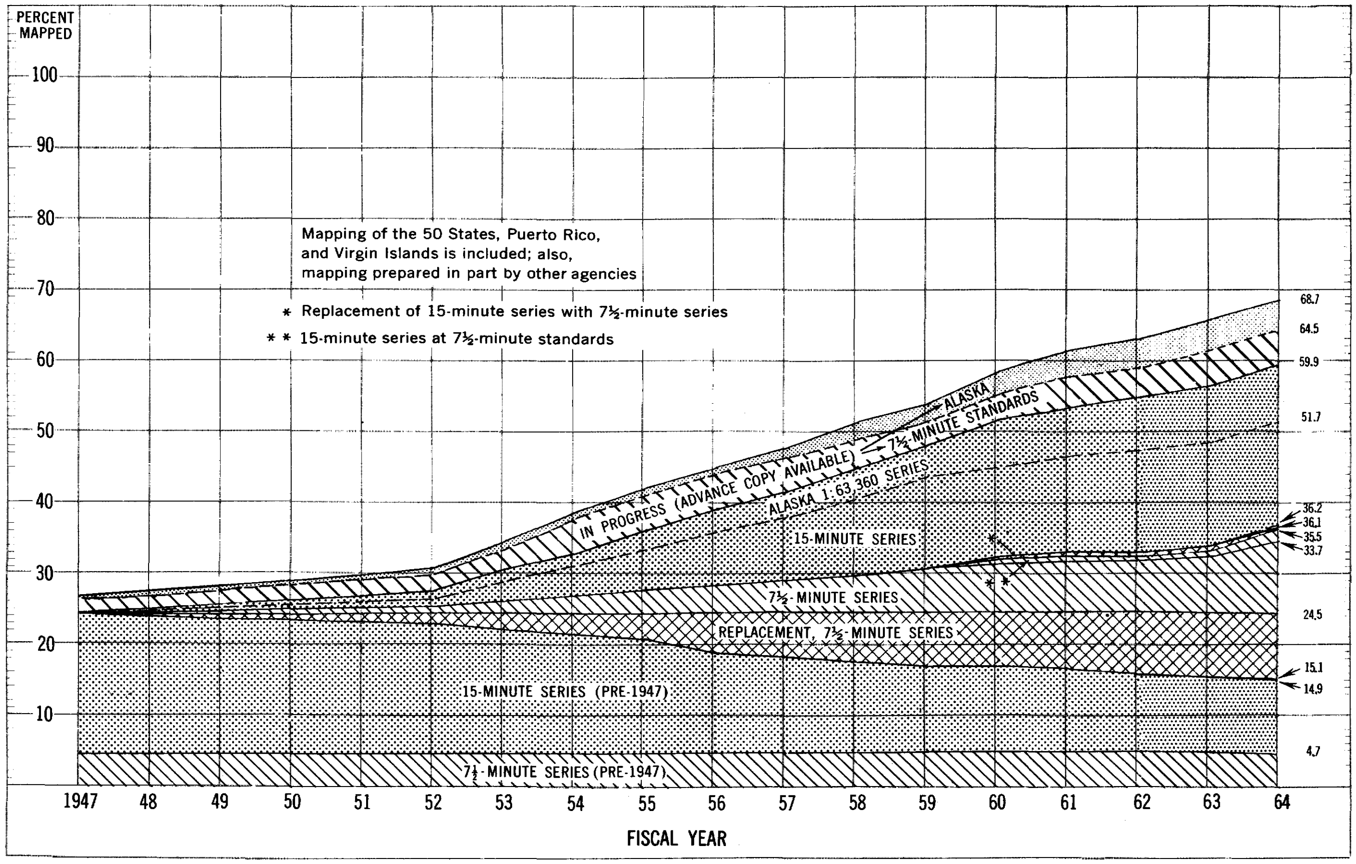

FIGURE 8.—Progress of 7½- and 15-minute quadrangle mapping.

cover a metropolitan area. Maps of 58 metropolitan areas have been published, including 1 new map and 1 revised map that were completed during fiscal 1964. Work in progress includes 1 new map and the revision of 4 others. Maps in the metropolitan-area series include:

PUBLISHED

Albuquerque, N. Mex.
Atlanta, Ga.
Austin, Tex.
Baton Rouge, La.
Boston, Mass.
Bridgeport, Conn.
Buffalo, N.Y.
Champaign-Urbana, Ill.
Chattanooga, Tenn.
Chicago, Ill. (3 sheets)
Cincinnati, Ohio
Cleveland, Ohio
Columbus, Ohio
Davenport–Rock Island–Moline, Iowa–Ill.
Dayton, Ohio
Denver, Colo.
Detroit, Mich. (2 sheets)
Duluth–Superior, Minn.–Wis.
Fort Worth, Tex.
Gary, Ind.
Hartford–New Britain, Conn.
Honolulu, Hawaii
Houston, Tex.
Indianapolis, Ind.
Juneau, Alaska
Knoxville, Tenn.
Little Rock, Ark.
Long Beach, Calif.
Los Angeles, Calif. (2 sheets)
Louisville, Ky.
Madison, Wis.
Milwaukee, Wis.
Minneapolis–St. Paul, Minn.
New Haven, Conn.
New Orleans, La.
New York, N.Y. (8 sheets)
Norfolk–Portsmouth–Newport News, Va.
Oakland, Calif.
Peoria, Ill.

Philadelphia, Pa. (2 sheets)
Pittsburgh, Pa.
Portland–Vancouver, Oreg.–Wash.
Rochester, N.Y.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
San Juan, P.R.
Seattle, Wash.
Shreveport, La.
Spokane, Wash.
Tacoma, Wash.
Toledo, Ohio
Washington, D.C.
Wichita, Kans.
Wilkes-Barre–Pittston, Pa.
Wilmington, Del.
Worcester, Mass.
Youngstown, Ohio

IN PROGRESS

New Maps

Anchorage, Alaska

Revision

Cincinnati, Ohio
Little Rock, Ark.
Louisville, Ky.
Washington, D.C.

National Park maps

Maps of 40 of the 201 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published and are available for distribution. These usually are made by combining all existing quadrangle maps of the area into one map sheet, but occasionally surveys are made covering only the park area. Most of the other parks, monuments, and historic sites are shown on maps of the standard quadrangle series. Published maps in the National Park series include:

Acadia National Park, Maine
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
Colonial National Historical Park (Yorktown), Va.
Colorado National Monument, Colo.
Crater Lake National Park, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Colo.-Utah
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz. (2 sheets)
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, N.C.-Tenn. (2 sheets)
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Olympic National Park, Wash.
Petrified Forest National Monument, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and Kings Canyon National Parks, Calif.
Shenandoah National Park, Va. (2 sheets)
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.
Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyo.-Mont.-Idaho
Yosemite National Park, Calif.
Yosemite Valley, Calif.
Zion National Park (Kolob Section), Utah
Zion National Park (Zion Canyon Section), Utah

Million-scale maps

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). The conterminous United States will be covered by 53 maps, 17 of which were produced before 1955. At that time the Army Map Service began a military series at 1:1,000,000 scale. Eventually this military series will be modified slightly and published in the IMW series (fig. 13).

Three of the maps, Hudson River, Mississippi Delta, and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Both the IMW and military series are available for Boston, Chesapeake Bay, Hatteras, Mount Shasta, and Point Conception. In addition, the American Geographical Society has published the Sonora, Chihuahua, and Monterrey maps; and Canada, the Regina and Montreal maps. Puerto Rico is covered by two maps, compiled by the American Geographical Society and published by both the Society and the Army Map Service.

Some maps of the military series have been modified for broader civil use by changing them to conform to the IMW sheet lines and sheet numbering system, but they do not meet IMW specifications in all respects. These maps are recognized by the United Nations Cartographic Office as provisional editions in the IMW series.

Work in progress includes two new maps, Lake Superior and Pikes Peak.

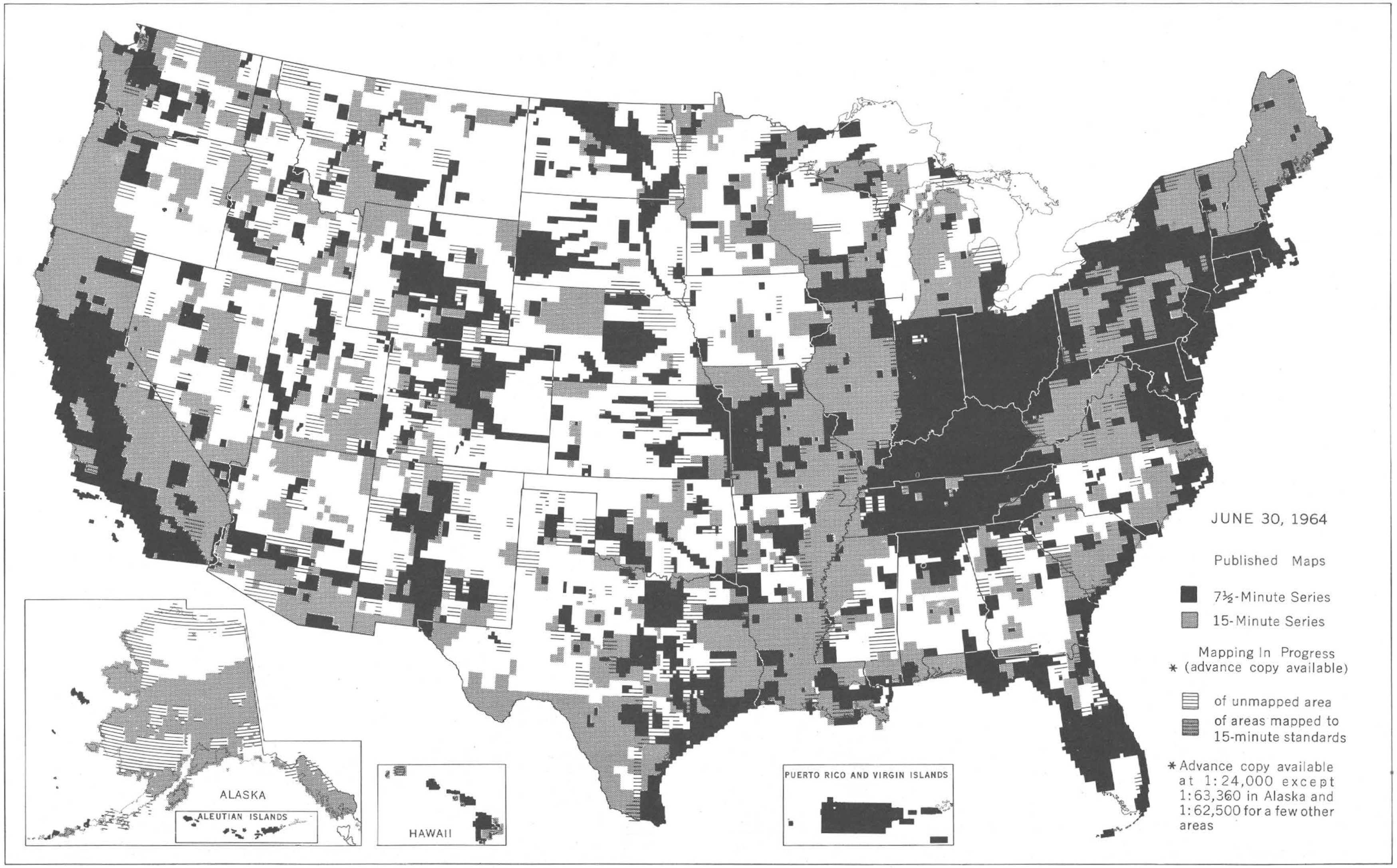

FIGURE 9.—Status of 7½- and 15-minute quadrangle mapping.

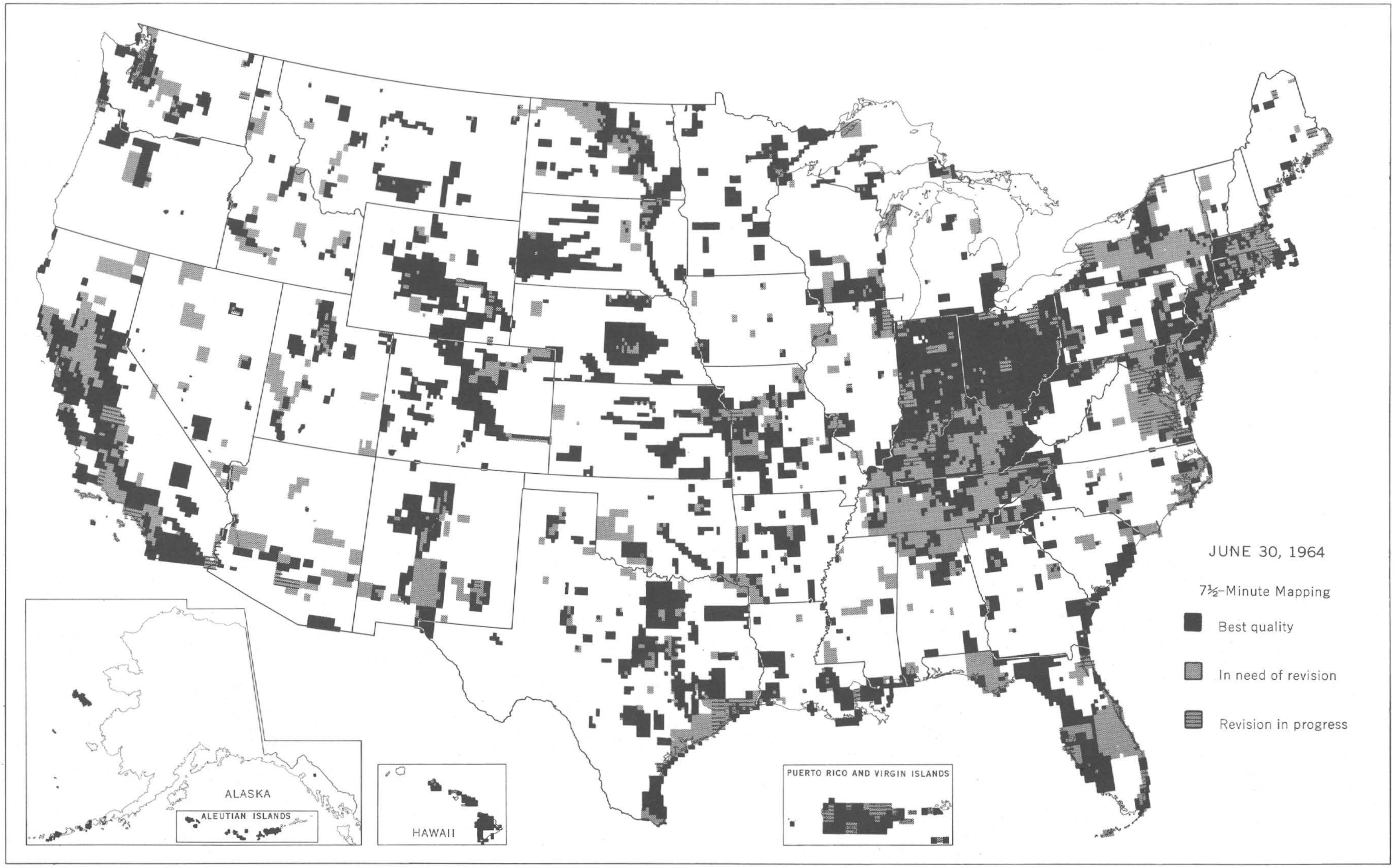

FIGURE 10.—Status of revision of large-scale mapping.

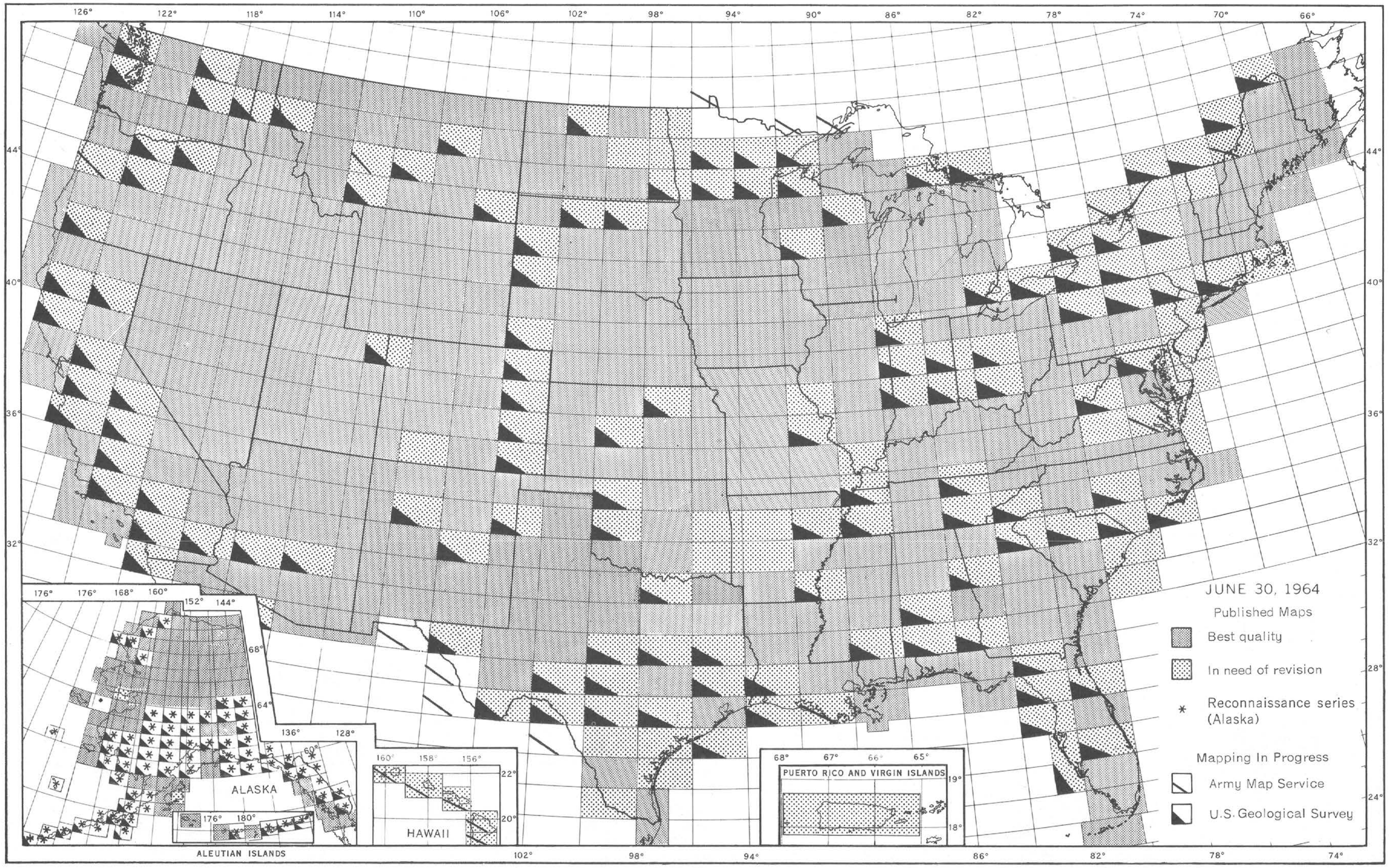

FIGURE 11.—Status of 1:250,000-scale mapping.

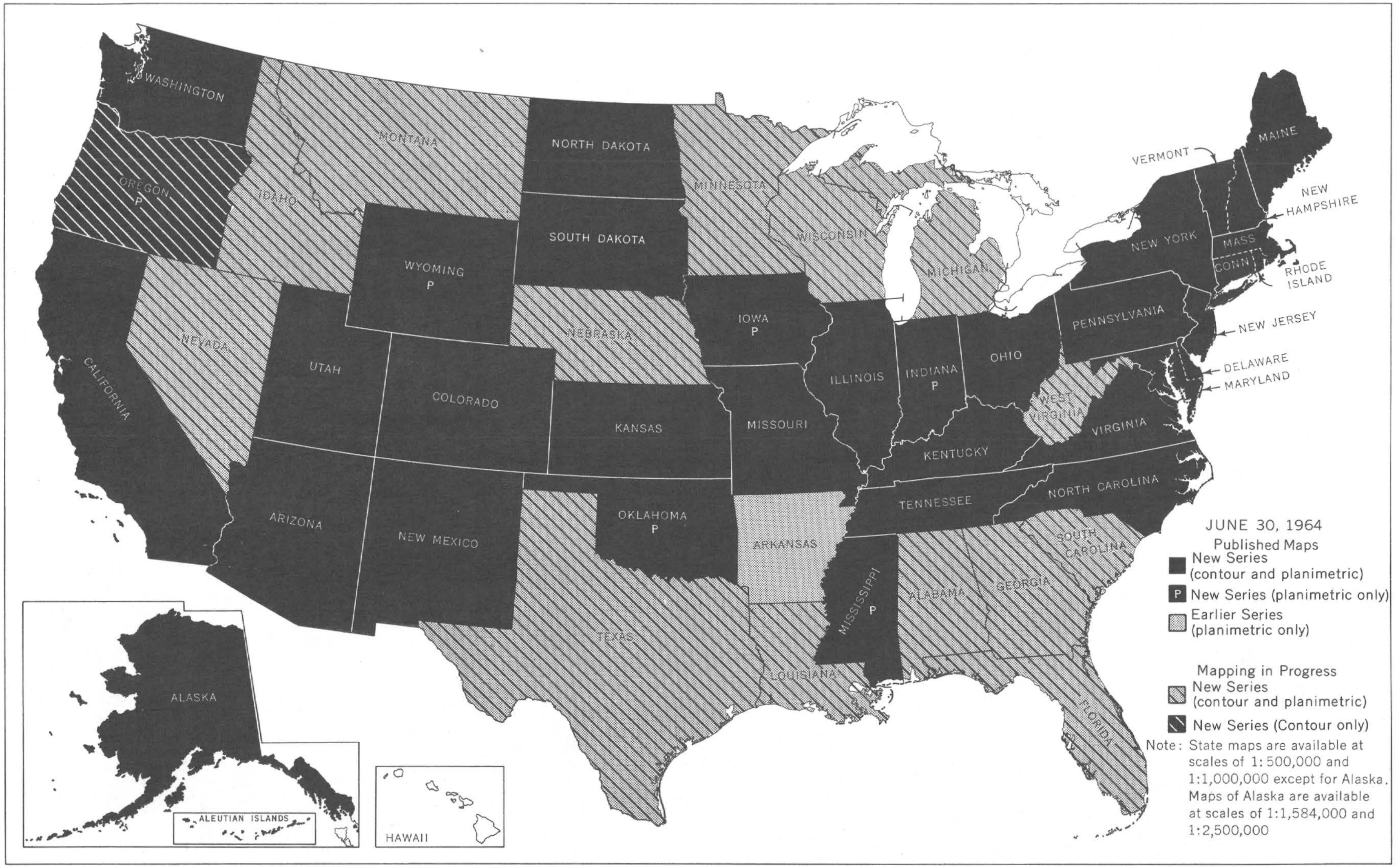

Figure 12.—Status of State maps.

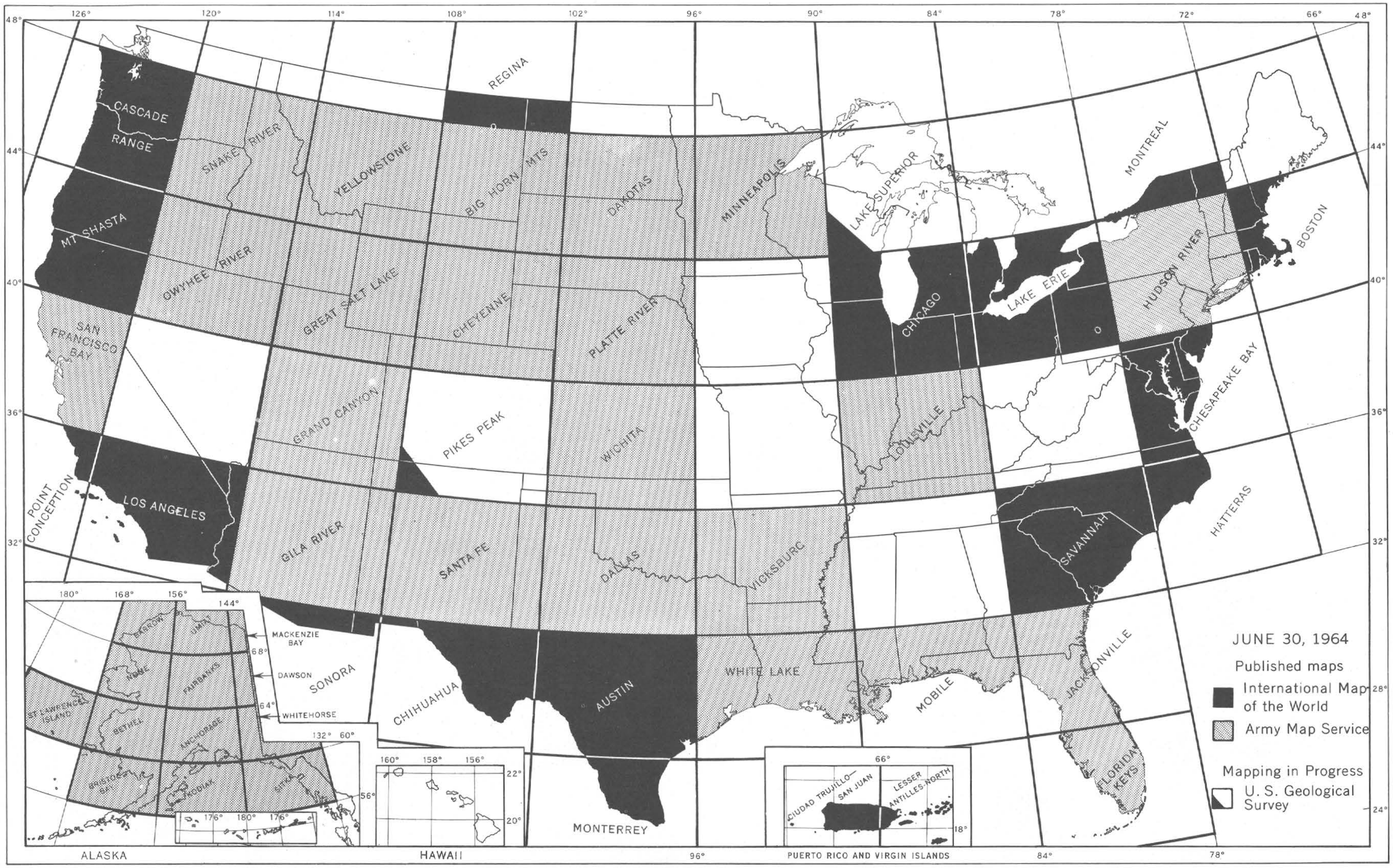

Figure 13.—Status of 1 : 1,000,000-scale topographic mapping.

MAPPING IN ANTARCTICA

The topographic mapping of Antarctica, conducted as a part of the U.S. Antarctic Research Program (USARP) of the National Science Foundation, was continued during fiscal 1964. Five topographic engineers went to Antarctica during the austral summer of 1963–64 to obtain geodetic control for the topographic mapping program and to execute surveys in support of other scientific disciplines. Also, a specialist in aerial photography was again assigned to Christchurch, New Zealand, for photographic liaison duty with the U.S. Navy.

Topographic field operations

D. C. Barnett and J. R. Heiser accompanied 4 geologists and 1 glaciologist of the Geological Survey to the Neptune Range of the Pensacola Mountains and executed 250 miles of electronic-distance traverse to control the Neptune Range for topographic mapping. These engineers also established a geodetic tie between control nets in the Patuxent Mountains and the Neptune Range, including a 45-mile electronic-distance measurement across an intervening glacier. In addition, they obtained 15 stellar and 5 solar observations at the previously established Patuxent Camp astronomic station.

Additional mapping control was established in the Ellsworth Mountains by Alfred Zavis. Supported by a U.S. Army helicopter detachment and assisted by geologists of the University of Minnesota, Zavis extended a previously established electronic-distance control net through the Heritage Range of the Ellsworth Mountains. The Camp Gould astronomic station, established during the 1962–63 field season, was strengthened by 18 additional stellar observations.

R. E. Kenfield and K. S. McLean established a precise ice-strain net originating at New Byrd Station and extending approximately 60 miles eastward toward the divide between the Filchner Ice Shelf and the Ross Ice Shelf. To obtain the required surveying accuracy of 1 part in 60,000, the engineers used theodolites for measuring angles and electronic equipment for measuring distances.

A large-scale topographic map of a portion of the Cape Hallett penguin rookery was also completed. Control previously established by the U.S. Navy was extended by using theodolites and electronic instruments. Two-foot contours were sketched by planetable methods.

Aerial photography

U.S. Navy Air Development Squadron 6 (VX–6) obtained aerial photographs for mapping in accordance with Geological Survey specifications. W. R. MacDonald was assigned to the U.S. Navy Photographic Laboratory at Christchurch, New Zealand, to advise on the quality of developed photographs and to assist with further planning and necessary reflights. In addition, MacDonald also served as visual navigator on all aerial photographic mapping missions over the Antarctic continent.

The aerial photography program was severly hampered by the lack of aircraft with suitable operational capabilities. LP–2J Neptune airplanes, previously used in Antarctica to photograph 400,000 square miles, were eliminated from the U.S. Naval aircraft inventory in 1963. Therefore, photographic missions had to be flown in a C–121J Constellation limited to operations from the ice runway at McMurdo. Final analysis of the season's photography indicates that areas totaling about 14,700 square miles were photographed acceptably for use in the Geological Survey mapping program.

Cartographic activities

Four 1:250,000-scale topographic maps of the Horlick Mountains were published in shaded-relief editions, making a total of 13 sheets at this scale now available. Mapping at the same scale is in progress for 12 sheets in the Queen Maud Range, 8 in the Queen Alexandra Range, 6 in the Britannia Range, 6 in the McMurdo area, and 19 in Victoria Land (fig. 14).

In support of biological studies by Johns Hopkins University, a topographic map of the Cape Crozier penguin rookery was photogrammetrically compiled at 1:2,400 scale, with contour intervals of 3 and 10 meters. Work is underway on a 1:500,000-scale shaded-relief map of northern Victoria Land, encompassing the area north of lat. 73° S., and between long. 158° and 171° E.

Antarctic relief model

The two-layer, multicolored plastic relief model of Antarctica, at the scale of 1:10,000,000, with a vertical exaggeration of 25:1, was completed, and 180 copies were distributed to individuals and organizations closely allied with scientific investigations in the Antarctic. In cooperation with the National Science Foundation, negotiations are underway to produce additional copies of the model for sale.

RESEARCH AND DEVELOPMENT

To support the Geological Survey program of topographic mapping, continuing research and development are needed to improve techniques, instruments, and media. The chief objectives are to improve the quality

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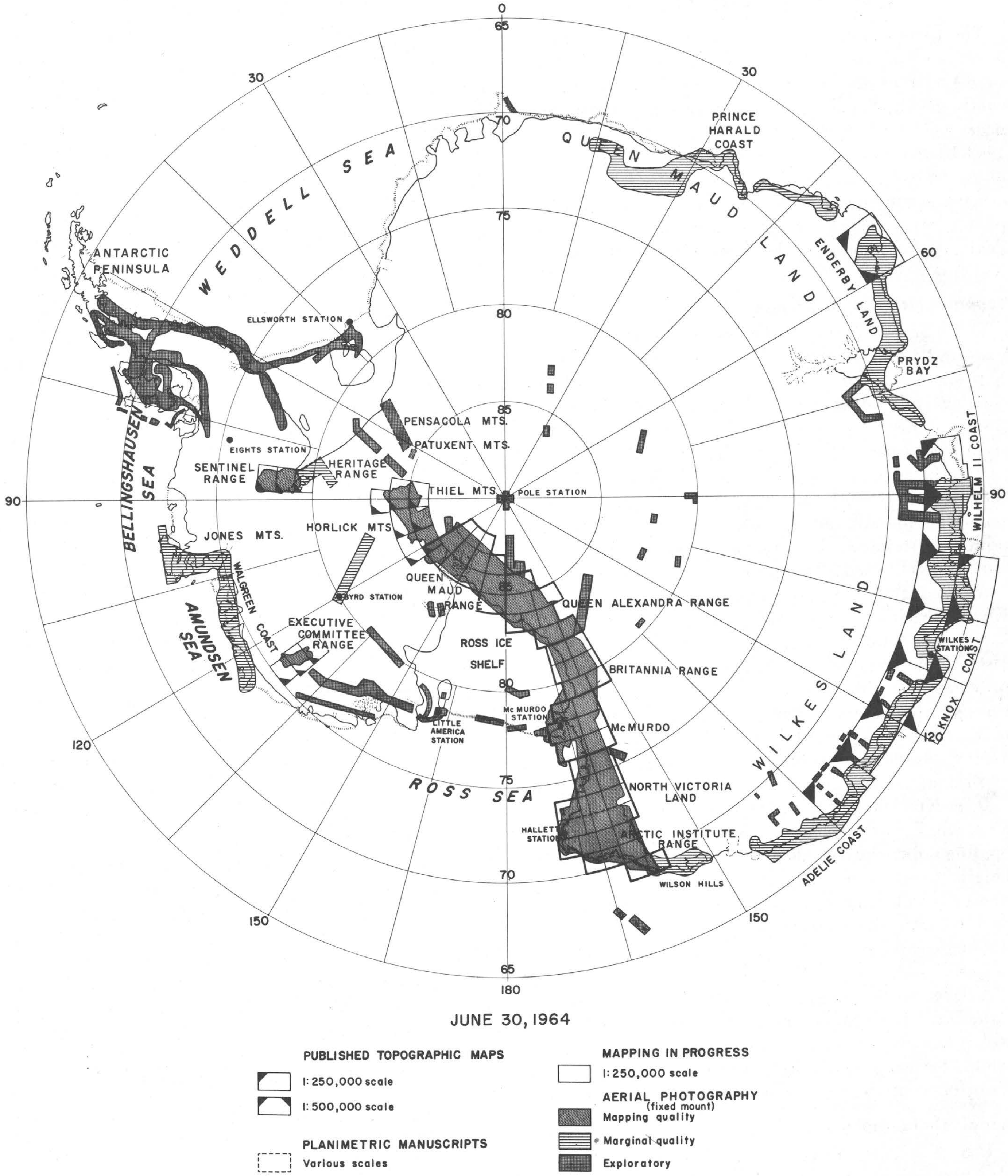

FIGURE 14.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1964.

and the usability of the maps produced and to reduce the cost of producing them.

As a part of this research, the Survey has tested a representative 10 percent of the quadrangles mapped, for two purposes: (1) to assure compliance with National Map Accuracy Standards and (2) to test the effectiveness of new methods and procedures.

In 1964, as a result of recent developments, the accuracy-testing program was reviewed and separated into its two basic parts. Henceforth, the area production offices will be responsible for planning and executing routine tests intended to supply data on compliance with National Map Accuracy Standards. Tests for evaluating new techniques and instrumentation will be planned specially and carried out on a prepared test site for which adequate control is available, thereby reducing variables to a minimum.

Major research projects in topographic surveying and mapping require a group effort by engineers and cartographers with different backgrounds and talents to achieve useful and meaningful results. Some of the results of projects carried out in 1964 are summarized below.

FIELD SURVEYS

Improvements in leveling

The evaluation of precise leveling instruments is a continuing program, started in 1962, in which new instruments are included as they become available. In 1963 the program was expanded to include a comprehensive study of errors in leveling and procedural techniques to reduce or eliminate them. The results of the error study have been discussed in a special report distributed to fieldmen of the Topographic Division and summarized in a paper given by R. J. Karren before the American Congress on Surveying and Mapping in March 1964. These reports recommend several modifications in observing and recording procedures that will effectively reduce or eliminate systematic errors.

Other means now being studied for improving the accuracy of leveling are more precise methods of graduating and calibrating level rods and applying corrections to the field observations. A photographic process for graduating rods appears promising and is being investigated in detail. A comparator has been modified for calibrating level rods, and its precision for that purpose is now being tested.

ABC survey system

Further research-production tests of the AirBorne Control (ABC) system were carried out in Maine in the fall of 1963. In this project, horizontal and vertical control stations were established on two 15-minute quandrangles consisting of densely wooded terrain. Towers were needed at all base stations, and for these the Survey portable aluminum towers gave excellent service. Despite unfavorable weather, nearly 200 control points were established in less than a month.

In this project, the helicopter was used for the first time as a target for photoidentifying control points. As the helicopter hovered over a point, a photographer in a light airplane flying at 2,000 feet obtained overlapping pictures. These stereoscopic photographs permit photogrammetrists in the office to relate control points precisely to the mapping photographs.

Antarctic astronomic position observations

Procedures for observing stars in daylight in Antarctica were improved significantly during the past season by star-finding charts constructed for the 16 brightest southern stars. From these the observer could quickly obtain time, direction, and altitude for crossings of the meridian and the prime vertical. By setting the theodolite to values scaled from the charts, observations could be completed without loss of time, an important consideration in cold weather. An additional advantage was improved accuracy of results based on balanced sets of observations, confined to the cardinal directions. Most positions were determined from at least 4 observations in each of the 4 cardinal directions, or a total of 16 star observations.

PHOTOGRAMMETRY

Super-wide-angle photogrammetric systems

Investigations of super-wide-angle photogrammetric mapping systems are continuing with evaluations of the resolution and flatness of stereomodels projected by the Wild B8 stereoplotter, Wild WH6 projectors, and Bausch and Lomb Balplex super-wide-angle projectors. Super-wide-angle photographs have been obtained over a test mapping area in Oklahoma and are being tested operationally in all these instruments. The Kern PG–2 plotter and the newly designed UDP–153 stereoplotter are scheduled for delivery in time to be included in the operational study. Field checks over the entire test area will be used to determine the planimetric and contouring capabilities of each super-wide-angle stereoplotting instrument.

Visual factors in stereoplotting

Under a research contract recently completed, Wendell E. Bryan, O.D., investigated the eye-fatigue and vision problems of a representative group of 60 employees operating anaglyphic double-projection stereoplotters. On the basis of optometric and medical examinations, the participants were furnished with prescription-ground anaglyphic glasses for stereocompilation, regular prescription glasses for normal activities, and special clip-on binocular loupes for scribing. An experimental stereoplotting room large enough for 17 plotting instruments was designed and constructed to determine the effects of a carefully controlled environment on morale, efficiency, and visual fatigue.

Participants expressed a decided preference for the controlled-environment room over conventional isolated stereoplotting booths. The work output of the group increased by more than 15 percent shortly after the introduction of optometric aids and an additional 8 percent when moved into the large, specially designed stereoplotting room.

Of particular significance was the finding that, with proper optometric care, the visual capabilities of older stereocompilers can be maintained at a level which will permit continued efficient productive use of their experience and skill.

Operational tests of modified Kelsh plotter

Operational tests of a modified Kelsh plotter have been completed. This plotter has lenses that provide an optimum projection distance of 550 mm rather than the standard 760 mm. The tests confirmed the expected advantages of smaller model scales, more favorable pantograph reduction ratios, and a 20-percent increase in illumination, as compared with the standard Kelsh plotter. Optical performance of the prototype lenses was tested by resolution readings, grid-flatness tests, and operational tests.

Subsequent investigation showed that it is feasible to combine the capabilities of the modified Kelsh plotter with those of the new super-wide-angle Kelsh plotter (projection distance, 440 mm) by means of interchangeable projector cones and lenses. These capabilities have been incorporated in the design of the new UDP–153 stereoplotter.

Mapping in dense evergreen timber

In a recent research study involving 18 photogrammetric compilers, James Halliday (p. C190–C194) determined the consistency of contouring in areas of dense evergreen timber for various combinations of photogrammetric parameters. With optimum conditions (that is, early spring photographic season, a *C*-factor of 700, no leaves on any deciduous trees in the area, and light snow cover on the ground) the vertical accuracy of the compilations was consistently high. No significant relation was found between the vertical accuracy attained and the contouring techniques used.

Because of the recurring difficulty of obtaining photographs under optimum conditions in these areas, studies are being continued to find new techniques for assisting the photogrammetrist in compilation. The ABC system is being evaluated as a means of providing more reliable photocontrol data for an area of dense evergreen woods in Maine. Airborne infrared sensors are also being investigated as a means of penetrating the foliage canopy and recording the ground data essential to topographic mapping.

Analytical aerotriangulation

A computer program has been written, for the Burroughs 220 computer, to establish map-coordinate positions for horizontal and vertical pass points used for orienting stereomodels in topographic map compliation. Input for the computer program consists of x and y photocoordinates measured with a precise comparator, horizontal and vertical ground-control data, and estimates of camera orientation and space position. Difficulties in the approximately 70 subroutines of the program have been checked and eliminated separately, and elimination of difficulties in the entire program is now in progress.

This program will solve aerotriangulation problems in 22-photograph blocks. Switches in the program permit a problem to be solved either in a true least-squares adjustment or, for speed and expediency, in a less rigorous least-squares solution. A supplementary adjustment permits contiguous 22-photograph blocks to be fitted together after they have been solved and adjusted internally.

Analytical adjustment of horizontal pass points

Several methods of mathematically establishing the map coordinates of horizontal pass points from stereomodel position data are being tested. In one method, pass points obtained from Kelsh-plotter stereomodels are joined analytically to form strips coinciding with the flight strips, and then cross strips transverse to the flight strips are formed by linking together sections from adjacent flights. That is, a section of the second strip is joined to an adjoining section in the first strip, an adjoining section in the third strip is joined to the section of the second strip, and so on. After the desired number of cross strips have been formed, each is adjusted to ground control, the regular strips are adjusted to the cross strips, and the resulting block is adjusted to all ground control. The data are computed and adjusted on an RPC–4000 electronic computer.

In the second method, the transformation factors needed to fit the pass points of one strip to those of an adjoining strip are computed. These factors are based on a comparison of the various combinations of corresponding line lengths and line azimuths formed from as many as 20 tie points common to two adjoining strips. After all strips are joined, the resulting block is adjusted to ground control by using the same approach as for the tie points between strips—that is, by comparing the observed line lengths and azimuths defined by the plotted and adjusted control points with the true line lengths and azimuths as determined by geodetic positions.

In the third method, the horizontal projection of the stereomodel is considered the basic unit being adjusted in a simultaneous least-squares block solution. The computer program will be flexible in that models, sections, strips, or blocks can be adjusted simultaneously in either linear or nonlinear conformal transformations.

Analytical vertical adjustment of a block of vertically bridged strips of aerial photographs

A prototype computer program for an analytical method of adjusting photogrammetrically determined elevations has been devised and tested. Input data were obtained from a stereoscopic vertical bridge of aerial photographs, using anaglyphic projectors. In this method, a vertical-error surface, linear in y and of second degree in x, is determined for each strip of a block in a least-squares solution, and the strips are fitted to each other and to control in an iterated adjustment. Although in the initial test the accuracy of the adjusted elevations did not meet the standards specified for field-surveyed photocontrol elevations, the results are sufficiently promising to warrant further investigation.

Rapid planimetric mapping

A research project to investigate a rapid method for compiling planimetric maps of unmapped areas in the conterminous United States, using readily available source materials, was completed. The project utilized high-altitude, wide-angle, 1:60,000-scale Army Map Service photographs and low-altitude, 8¼-inch Department of Agriculture photographs.

Control was extended over a 30-minute-square area by means of a stereotemplet assembly at 1:24,000 scale, based on horizontal control at 10- to 15-minute intervals around the perimeter of the area. The stereotemplets were plotted from the AMS photographs. The root mean square error of 92 test points was 12.7 feet.

Skeletal frameworks of readily interpretable planimetry were compiled for two 7½-minute quadrangles, using the AMS photographs in Kelsh plotters. Root mean square errors for these compilations were 13 and 15 feet, and all points tested were accurate within 40 feet.

The rest of the main map details were added to the manuscripts by monoscopic transfer from the Department of Agriculture photographs. Completeness of content of the final manuscripts was evaluated by comparing them with published 7½-minute topographic maps. This comparison showed that, for example, 89 percent of the buildings on the published maps had been plotted on the map made by the rapid compilation method.

Two additional test projects in other areas are now being planned to determine whether the favorable results of the first project can be obtained consistently.

CARTOGRAPHY

Cartographic treatment of orthophotomosaics

Experiments are continuing in the development of cartographic treatment of orthophotomosaics for publication as orthophotomaps. An orthophotomap covering the 7½-minute Cave Creek 2 SE, Ariz., quadrangle is in preparation. The experimental printing will illustrate the use of photographic imagery, in color, combined with the overprinted information to portray a sparsely settled arid area. An earlier experimental map covered the urban area including Roanoke, Va. (M. B. Scher, chapter D). This form of map presentation appears to be particularly advantageous in these two kinds of areas.

Processing geographic names

Applications of electronic data-processing systems to storage and retrieval of geographic names is being investigated. The objective is a system that will store cumulative pertinent data on official standard names and Board on Geographic Names decisions and will print out, on call, geographic information in selected categories or listings. This capability will greatly facilitate publication of Decision Lists reflecting actions by the Board on Geographic Names, compilation of gazetteers of place names for the individual States, replies to correspondence, and other uses of the stored data.

COOPERATING AGENCIES FOR FISCAL YEAR 1964

FEDERAL AGENCIES

Agency for International Development
Air Force:
- Cambridge Research Center
- Special Weapons Center
- Technical Application Center

Army:
- U.S. Army—Europe
- Corps of Engineers, Waterways Experiment Station

Atomic Energy Commission:
- Division of Military Application
- Division of Peaceful Nuclear Explosives
- Division of Raw Materials
- Division of Reactor Development
- Nevada Operations Office
- Research Division
- San Francisco Operations Office

Department of Agriculture:
- Forest Service
- Soil Conservation Service

Department of Commerce:
- Bureau of Public Roads
- Bureau of Standards

Department of Defense:
- Advanced Research Projects Agency
- Defense Atomic Support Agency
- Defense Intelligence Agency
- Office of Scientific Research

Department of Health, Education, and Welfare:
- Public Health Service

Department of the Interior:
- Bonneville Power Administration
- Bureau of Commercial Fisheries
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- National Park Service
- Office of Minerals Exploration
- The Alaska Railroad

Department of Justice
Department of State
District of Columbia
Executive Office of the President—Office of Emergency Planning
Federal Power Commission
Navy:
- Bureau of Yards and Docks
- Office of Naval Research

National Aeronautics and Space Administration
National Science Foundation
Tenessee Valley Authority
Veterans Administration

STATE, COUNTY, AND MUNICIPAL AGENCIES

Alabama:
- Geological Survey of Alabama
- Alabama Highway Department
- Department of Conservation
- Water Improvement Commission
- Calhoun County Board of Revenue
- City of Huntsville
- City of Mobile

Alaska:
- Department of Highways
- City of Anchorage

Arizona:
- Arizona Highway Department
- State Land Department
- Regents of the University of Arizona
- Superior Court, County of Apache
- Maricopa County Flood Control District
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- City of Flagstaff

Arizona—Continued
- City of Prescott
- City of Tucson
- City of Williams
- Buckeye Irrigation Company
- Gila Valley Irrigation District
- Salt River Valley Water Users Association
- San Carlos Irrigation and Drainage District

Arkansas:
- Arkansas Geological and Conservation Commission
- Arkansas Game and Fish Commission
- Arkansas State Highway Commission
- University of Arkansas—Agricultural Experiment Station

California:
- Department of Conservation, Division of Mines and Geology
- State Department of Water Resources
- State Department of Fish and Game
- State Department of Parks and Recreation
- State Water Pollution Control Board
- Alameda County Flood Control and Water Conservation District

California—Continued
- Alameda County Water District
- Calaveras County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Los Angeles Department of County Engineers
- Lake County Flood Control and Water Conservation District
- Montecito County Water District
- Monterrey County Flood Control and Water Conservation District
- Orange County Flood Control District
- Sacramento County
- San Bernardino County Flood Control District
- San Francisco City and County Public Utilities Commission
- San Luis Obispo County Flood Control and Water Conservation District
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water Conservation District
- Santa Cruz County Flood Control and Water Conservation District
- City of Arcata
- City of San Diego
- San Francisco Water Department
- Santa Barbara Water Department
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Antelope Valley—East Kern Water Agency
- Imperial Irrigation District
- Metropolitan Water District of Southern California
- Palo Verde Irrigation District
- San Bernardino Valley Water Conservation District
- Santa Maria Valley Water Conservation District
- Ventura River Municipal Water District
- Western Municipal Water District of Riverside County

Colorado:
- Colorado State Metal Mining Fund Board
- Colorado Water Conservation Board
- Office of State Engineer, Division of Water Resources
- Colorado State University Agricultural Experiment Station
- Colorado Springs—Department of Public Utilities
- Denver Board of Water Commissioners
- City of Westminster
- Arkansas River Compact Administration
- Costilla Creek Compact Commission
- Rio Grande Compact Commission
- Southeastern Colorado Water Conservancy District

Connecticut:
- Connecticut Geologic and Natural History Survey
- Highway Department
- State Water Resources Commission
- Greater Hartford Flood Commission
- Hartford Department of Public Works
- New Britain Board of Water Commissioners
- City of Torrington—Engineering Department

Delaware:
- Delaware Geological Survey
- State Highway Department

District of Columbia:
- District of Columbia Department of Sanitary Engineering

Florida:
- Florida Geological Survey
- State Board of Parks and Historic Memorials
- State Road Department
- Broward County—Board of County Commissioners
- Collier County—Board of County Commissioners
- Dade County—Board of County Commissioners
- Hillsborough County—Board of County Commissioners
- Orange County—Board of County Commissioners
- Pinellas County—Board of County Commissioners
- Polk County—Board of County Commissioners
- City of Boca Raton
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Jacksonville—City Commission
- City of Jacksonville—Office of the City Engineer
- City of Miami—Department of Water and Sewerage
- City of Miami Beach
- City of Naples
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Central and Southern Florida Flood Control District
- Southwest Florida Water Management District
- Trustees of Internal Improvement Fund

Georgia:
- Department of Mines, Mining and Geology, Division of Conservation
- State Highway Department

Hawaii:
- State Department of Land and Natural Resources
- Honolulu, City and County of

Idaho:
- Idaho Department of Reclamation
- Idaho Department of Highways
- Idaho Department of Fish and Game

Illinois:
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education
- Fountain Head Drainage District
- Metropolitan Sanitary District of Greater Chicago
- Northeastern Illinois Metropolitan Area Planning Commission
- Sanitary District of Bloom Township (Cook County)

Indiana:
- State Department of Conservation
- Division of Water Resources
- State Highway Commission
- Flood Control and Water Resources Commission
- Board of Health

Iowa:
- Iowa Geological Survey
- Iowa State Conservation Commission
- Iowa State Highway Commission
- Iowa Institute of Hydraulic Research
- Iowa State University—Agricultural Experiment Station
- Linn County—Board of Supervisors
- City of Cedar Rapids
- City of Fort Dodge—Department of Utilities

Iowa—Continued
- City of Iowa City
- City of Muscatine

Kansas:
- Kansas State Geological Survey
- State Water Resources Board
- State Department of Health—Environmental Health Services
- State Highway Commission
- State Board of Agriculture, Division of Water Resources
- City of Wichita—Department of Public Works

Kentucky:
- Kentucky Geological Survey

Louisiana:
- State Department of Public Works
- State Department of Conservation
- State Department of Highways
- Sabine River Compact Commission

Maine:
- Department of Public Works
- Maine Public Utilities Commission
- State Highway Commission

Maryland:
- Maryland Geological Survey
- State Department of Health
- State Planning Department
- State Roads Commission
- Baltimore County—Department of Public Works
- City of Baltimore
- City of Salisbury
- Washington Suburban Sanitary Commission

Massachusetts:
- Massachusetts Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Massachusetts Water Resources Commission
- Boston Metropolitan District Commission

Michigan:
- State Water Resource Commission
- Michigan Department of Conservation, Geological Survey Division
- State Highway Department

Minnesota:
- Minnesota Geological Survey
- State Department of Conservation:
  - Division of Waters
  - Department of Conservation
- State of Minnesota Department of Highways
- Department of Iron Range Resources and Rehabilitation
- Board of County Commissioners of Hennepin County

Mississippi:
- Mississippi Board of Water Commissioners
- Mississippi State Highway Department
- Mississippi Industrial and Technological Research Commission
- Harrison County—Board of Supervisors and Development Commission
- Jackson County—Port Authority
- City of Jackson
- Pearl River Valley Water Supply District

Missouri:
- Division of Geological Survey and Water Resources
- State Highway Commission
- Water Pollution Control Board
- Curators of the University of Missouri

Montana:
- Montana Bureau of Mines and Geology
- State Engineer
- State Fish and Game Commission
- State Highway Commission
- State Water Conservation Board
- Montana State College—Endowment and Research Foundation

Nebraska:
- Department of Water Resources
- Department of Roads
- University of Nebraska—Conservation and Survey Division
- Nebraska Mid-State Reclamation District

Nevada:
- Nevada Bureau of Mines
- Department of Conservation and Natural Resources
- Department of Highways

New Hampshire:
- New Hampshire Water Resources Board

New Jersey:
- Department of Conservation and Economic Development
  - Division of Water Policy and Supply
  - Division of Fish and Game
- Department of Health
- Department of Agriculture
- Rutgers University, the State University of New Jersey
- Camden County Planning Board
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Delaware River Basin Commission

New Mexico:
- State Engineer
- State Highway Department
- State Game and Fish Commission
- State Bureau of Mines and Mineral Resources Division, New Mexico Institute of Mining and Technology
- Interstate Stream Commission
- Pecos River Commission
- Pecos Valley Artesian Conservancy District
- Rio Grande Compact Commission
- Costilla Creek Compact Commission
- City of Ruidoso

New York:
- State Conservation Department:
  - Division of Lands and Forests
  - Division of Water Resources
- State Department of Commerce
- State Department of Health
- State Department of Public Works
- New York Water Resources Commission
- Office of Atomic Development
- Board of Hudson River—Black River Regulating District
- Dutchess County Board of Supervisors
- Nassau County Department of Public Works
- Onondaga County Department of Public Works

New York—Continued
- Onondaga County Water Authority
- Suffolk County Board of Supervisors
- Suffolk County Water Authority
- Westchester County Department of Public Works
- City of Albany—Department of Water and Water Supply
- City of Auburn—Water Department
- New York City Board of Water Supply
- New York City Department of Water Supply, Gas and Electricity
- Village of Nyack—Board of Water Commissioners
- Brighton Sewer District No. 2
- Oswegatchie River—Cranberry Reservoir Commission

North Carolina:
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- State Department of Water Resources
- State Highway Commission
- Pitt County Board of Commissioners
- City of Asheville
- City of Burlington
- City of Charlotte
- City of Durham
- City of Greensboro
- Town of Waynesville

North Dakota:
- State Water Conservation Commission
- North Dakota Geological Survey
- State Highway Department

Ohio:
- Ohio Department of Natural Resources—Division of Water
- Ohio Department of Health
- Ohio Department of Highways
- City of Columbus—Department of Public Service
- Miami Conservancy District
- Ohio River Valley Water Sanitation Commission
- Scioto Conservancy District

Oklahoma:
- Oklahoma Water Resource Board
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma State Department of Health
- Oklahoma City Water Department

Oregon:
- State Engineer
- State Highway Department
- Board of Higher Education
- State Game Commission
- County of Coos—Board of Commissioners
- County Court of Douglas County
- County Court of Lane County
- County Court of Morrow County
- City of Dallas
- City of Dalles City
- City of Eugene—Water and Electric Board
- City of McMinnville—Water and Light Department
- City of Portland—Bureau of Water Works
- City of Toledo
- Coos Bay—North Bed Water Board
- Burnt River Irrigation District
- Mosier Irrigation District

Oregon—Continued
- Talent Irrigation District
- Vale Irrigation District

Pennsylvania:
- Pennsylvania Bureau of Topographic and Geologic Survey
- State Department of Forests and Waters
- State Department of Agriculture
- State Department of Health
- City of Bethlehem
- City of Harrisburg
- City of Philadelphia
- Conestoga Valley Association, Inc.

Rhode Island:
- Rhode Island Water Resources Coordinating Board
- Department of Public Works—Division of Harbors and Rivers

South Carolina:
- State Development Board
- State Highway Department
- State Public Service Authority
- State Water Pollution Control Authority
- City of Spartanburg—Public Works Department

South Dakota:
- South Dakota Geological Survey
- South Dakota Water Resources Commission
- South Dakota Department of Highways

Tennessee:
- Tennessee Department of Conservation:
  - Division of Water Resources
  - Division of Geology
- Tennessee Department of Highways
- Tennessee Department of Public Health
- Tennessee Game and Fish Commission
- City of Chattanooga
- City of Murfreesboro—Water and Sewer Department
- Memphis Board of Light, Gas, and Water Commissioners—Water Division
- Metropolitan Government of Nashville and Davidson County—Department of Public Works

Texas:
- Texas Water Commission
- Pecos River Commission
- Rio Grande Compact Commission
- Sabine River Compact Administration
- City of Dallas
- City of Houston

Utah:
- Utah Geological and Mineralogical Survey
- Utah State Engineer
- Utah Water and Power Board
- State Road Commission of Utah
- Salt Lake County
- Bear River Compact Commission

Vermont:
- Vermont Geological Survey
- State Water Resources Board
- Department of Highways

Virginia:
- Department of Conservation and Development—Division of Mineral Resources
- Department of Highways

Virginia—Continued
- Division of Industrial Development and Planning
- County of Chesterfield
- County of Fairfax
- City of Alexandria
- City of Charlottesville
- City of Newport News—Department of Public Utilities
- City of Norfolk—Division of Water Supply
- City of Roanoke
- City of Staunton

Washington:
- State Department of Conservation:
  - Division of Mines and Geology
  - Division of Water Resources
- State Department of Fisheries
- State Department of Game
- State Department of Highways
- State Pollution Control Commission
- King County Board of Commissioners
- Municipality of Metropolitan Seattle
- City of Seattle
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works

West Virginia:
- State Department of Natural Resources
- State Geological and Economic Survey

West Virginia—Continued
- State Road Commission
- Clarksburg Water Board

Wisconsin:
- University of Wisconsin—Geological and Natural History Survey
- Public Service Commission of Wisconsin
- State Committee on Water Pollution
- State Highway Commission
- Madison Metropolitan Sewerage District
- Southeastern Wisconsin Regional Planning Commission

Wyoming:
- Geological Survey of Wyoming
- State Engineer
- Wyoming Highway Department
- Wyoming Natural Resource Board
- City of Cheyenne—Board of Public Utilities

Commonwealth of Puerto Rico:
- Water Resources Authority
- Department of Public Works

American Samoa:
- Government of American Samoa

Guam:
- Government of Guam

Virgin Islands of the United States:
- Government of the Virgin Islands

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets NW., Washington, D.C. 20242; 343–1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; BElmont 3–3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; DAvenport 5–6761

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage, 99501	Margaret I. Erwin (BRoadway 2–8791)	108 Skyline Bldg., 508 2d Ave.
California, Los Angeles, 90014	Lucy E. Birdsall (688–2850)	1031 Bartlett Bldg., 215 West 7th St.
San Francisco, 94111	Jean V. Molleskog (556–5627)	504 Custom House, 555 Battery St.
Colorado, Denver, 80202	Lorene C. Young (297–4169)	468 New Custom House.
Utah, Salt Lake City, 84111	Maurine Clifford (524–5652)	8102 Federal Office Bldg., 125 South State St.
Texas, Dallas, 75202	Mary E. Reid (RIverside 8–5611, ext. 3230)	602 Thomas Bldg., 1314 Wood St.
Washington, Spokane, 99204	Eva M. Raymond (TEmple 8–2084, ext. 30)	South 157 Howard St.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of September 1964. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

CONSERVATION DIVISION

Location	*Official in charge* and telephone number*	*Address*
Alaska, Anchorage, 99501	Leo H. Saarela (m) (BRoadway 7–3883), Alexander A. Wanek (c) (BRoadway 2–8262), and Merwin H. Soyster (o) (BRoadway 2–8262).	P.O. Box 259; 62, 12 (or 15), and 13 Federal Bldg.
California, Los Angeles, 90014	Russell G. Wayland (c) (688–2849) and D. W. Solonas (o) (688–2846).	1012 Bartlett Bldg., 215 West 7th St.
Sacramento, 95814	Richard N. Doolittle (w) (449–2203)	8030 Federal Bldg., 650 Capitol Ave.
Taft, 93268	Harry Lee Wolf (o) (ROger 5–4234) and E. E. Richardson (c) (ROger 5–4234).	P.O. Box CC.
Colorado, Denver, 80202	G. G. Frazier (o) (534–4151, ext. 356) and H. B. Lindeman (m) (534–4151, ext. 278).	448 and 456 New Custom House.
Denver, 80225	George H. Horn (c) (233–3611, ext. 8168)	Federal Center.
Denver, 80202	Wm. C. Senkpiel (w) (534–4151, ext. 1389)	816 University Bldg., 910 16th St.
Durango, 81302	Jerry W. Long (o) (247–5144)	P.O. Box 1809; Jarvis Bldg., 125 West 10th St.
Louisiana, New Orleans, 70113	Admiral D. Acuff (o) (527–6543)	T-6009 Federal Bldg., 701 Loyola Ave.
Lafayette, 70501	Robert M. Bennett (b) (CEnter 4–1637)	P.O. Box 3884; 301 Federal Bldg., Jefferson and Main Sts.
Montana, Billings, 59101	Ray M. Bottomley (m) (252–2280) and Hillary A. Oden (o) (252–2880).	P.O. Box 2250; 323 and 327 Federal Bldg.
Great Falls, 59401	Andrew F. Bateman (c) (452–2008)	P.O. Box 2265; 510 First Ave. North.
	John A. Fraher (o) (453–6901)	P.O. Box 1215; 510 First Ave. North.

*The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: b—Branch of Connally Act Compliance, c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification.

Location	Official in charge* and telephone number	Address
New Mexico, Artesia, 88210	James A. Knauf (o) (746–4841)	Drawer U; 210 Carper Bldg., 105 South 4th St.
Carlsbad, 88220	Robert S. Fulton (m) and Bruno R. Alto (c) (TUxedo 5–6454).	P.O. Box 1716; 504A North Canal St.
Farmington, 87401	Phillip T. McGrath (o) and J. E. Fassett (c) (325–4572).	P.O. Box 959; 409 Petroleum Club Plaza Bldg., 3535 East 30th St.
Hobbs, 88240	Arthur R. Brown (o) (EXpress 3–3612)	Box 1157; 205 North Linam St.
Roswell, 88201	J. A. Anderson (o) and T. F. Stipp (c) (622–1332)	P.O. Drawer 1857; Farnsworth Bldg., 120 West 2d St.
Oklahoma, Holdenville, 74848	Gerhardt H. W. Schuster (o) (Franklin 9–3840)	P.O. Box 789; 5 Federal Bldg.
McAlester, 74502	A. M. Dinsmore (m) (GArden 3–5030)	509 South 3d St.
Miami, 75354	Andrew V. Bailey (m) (KImball 2–9481)	P.O. Box 509; 205 Federal Bldg.
Oklahoma City, 73102	Charley W. Nease (o) (CEntral 6–2311)	4321 Federal Court House and Office Bldg., 220 N.W. 4th St.
Tulsa, 74103	Edward L. Johnson (c) and N. Orvis Frederick (o) (LUther 4–7161, ext. 638).	521 Wright Bldg., 115 West 3d St.
Oregon, Portland, 97208	Loyd L. Young (w) (226–3361, ext. 1252)	P.O. Box 3087; 319 Post Office Bldg.
Texas, Kilgore, 75662	Warren W. Mankin (b) (5564)	P.O. Box 1230; Rader Bldg., 901–903 Broadway Blvd.
Midland, 79701	Everett H. Patterson (b) (MUtual 4–6741)	P.O. Box 1830; 805 Petroleum Life Bldg., Texas and Colorado Sts.
Victoria, 77901	John I. Watson (b) (HIllcrest 5–1841)	P.O. Box 2550; 228 Federal Bldg., Main and Church Sts.
Utah, Salt Lake City, 84111	Ernest Blessing (m) (524–5646), Harry McAndrews (c) (524–5650), and Rodney A. Smith (o) (524–5650).	420, 450, and 416 Empire Bldg., 231 East 4th St.
Washington, Tacoma, 98402	Gordon C. Giles (w) (MArket 7–1271)	P.O. Box 1152; 244 Federal Bldg.
Wyoming, Casper, 82602	J. R. Schwabrow (o) and Donald M. Van Sickle (c) (237–2561).	P.O. Box 400; 305 Federal Bldg.
Newcastle, 82701	Glenn E. Worden (o) (746–4554)	P.O. Box 231; 611 South Summit St.
Rock Springs, 82901	John Duletsky (o) (362–6422) and Arne A. Mattila (m) (362–7350).	P.O. Box 1170; 201 and 219 First Security Bldg., 502 South Front St.
Thermopolis, 82443	Charles P. Clifford (o) (864–3477)	P.O. Box 590; 202 Federal Bldg.

GEOLOGIC DIVISION

Location	Geologist in charge and telephone number	Address
Alaska, College, 99735	Robert M. Chapman (479–6725)	P.O. Box 580; Brooks Memorial Bldg.
Arizona, Flagstaff, 86002	Eugene M. Shoemaker (774–5081)	P.O. Box 1906.
California, Los Angeles 90424	John T. McGill (GRanite 3–0971, ext. 9881)	Geology Bldg., Univ. of California.
Hawaii, Hawaii National Park, 96718	Howard A. Powers (678–485)	Hawaiian Volcano Observatory.
Kansas, Lawrence, 66044	Windsor L. Adkison (VIking 3–2700)	c/o State Geological Survey, Lindley Hall, Univ. of Kansas.
Kentucky, Lexington, 40503	Paul W. Richards (4–2473)	496 Southland Drive.
Maryland, Beltsville, 20705	Louis Pavlides (GRanite 4–4800, ext. 468)	U.S. Geological Survey Bldg., Dept. of Agriculture Research Center.
Massachusetts, Boston, 02116	Lincoln R. Page (KEnmore 6–1444)	270 Dartmouth St., Rm. 1.
New Mexico, Albuquerque, 87100	Charles B. Read (CHapel 7–0311, ext. 483)	P.O. Box 4083, Station A; Geology Bldg., Univ. of New Mexico.
Ohio, Columbus, 43200	James M. Schopf (AXminister 4–1810)	Orton Hall, Ohio State Univ., 155 Oval Drive.
Pennsylvania, Mt. Carmel, 17851	Jacques F. Robertson (339–4390)	P.O. Box 366; 56 West 2d St.
Puerto Rico, Roosevelt, 00927	Watson H. Monroe (San Juan 6–5340)	P.O. Box 803.

*See footnote, p. A227.

Location	Geologist in charge and telephone number	Address
Tennessee, Knoxville, 37902	Robert A. Laurence (2–7787)	11 Post Office Bldg.
Texas, Austin, 78705	D. Hoye Eargle (HObart 5–6501)	P.O. Box 189; Balcones Research Center, Route 4.
Houston, 77030	A. L. Chidester (774–5081)	P.O. Box 1906; Flagstaff, Ariz. 86002.
Utah, Salt Lake City, 84111	Lowell S. Hilpert (524–5640)	8426 Federal Bldg.
Washington, Spokane, 99204	Albert E. Weissenborn (TEmple 8–2084)	South 157 Howard St.
Wisconsin, Madison, 53706	Carl E. Dutton (262–1854)	222 Science Hall, Univ. of Wisconsin.
Wyoming, Laramie, 82070	J. David Love (FRanklin 5–4495)	Geology Hall, Univ. of Wyoming.

TOPOGRAPHIC DIVISION

Location	Engineer in charge and telephone number	Address
California, Menlo Park, 94025	Robert O. Davis (415 325–6761, ext. 411)	345 Middlefield Rd.
Colorado, Denver, 80225	Roland H. Moore (303 233–3611, ext. 8551)	Federal Center Bldg. 25.
Missouri, Rolla, 65401	Daniel Kennedy (314 364–3680)	P.O. Box 133; 9th and Elm Sts.
Virginia, Arlington, 22201	Charles F. Fuechsel (703 JAckson 5–7550)	1109 N. Highland St.

WATER RESOURCES DIVISION

Location	Official in charge* and telephone number	Address
	Area Offices	
Atlantic Coast Area Arlington, Va., 20242.	George E. Ferguson, Division Hydrologist (202 343–4840).	George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Midcontinent Area St. Louis, Mo., 63103.	Harry D. Wilson, Jr., Division Hydrologist (314 622–4361).	1252 Federal Bldg., 1520 Market St.
Rocky Mountain Area Denver, Colo., 80225.	Sherman K. Jackson, Division Hydrologist (303 233–3611).	Federal Center, Bldg. 25.
Pacific Coast Area Menlo Park, Calif., 94025.	Warren W. Hastings, Division Hydrologist (415 325–6761).	345 Middlefield Rd.
	District Offices	
Alabama, University, 35486	William J. Powell (g) and Lamar E. Carroon (s) (205 752–8105).	P.O. Box V; Oil and Gas Board Bldg., Univ. of Alabama.
Alaska, Anchorage, 99501	Melvin V. Marcher (g) (Broadway 2–8333)	P.O. Box 393; 311 Federal Bldg.
Juneau, 99801	Ralph E. Marsh (s) (907 586–2815)	P.O. Box 2659; 203 Simpson Bldg., 222 Seward St.
Palmer, 99645	Robert G. Schupp (q) (907 745–3115)	P.O. Box 36; Wright Bldg.
Arizona, Tucson, 85717	Horace M. Babcock (w) (602 623–7731, ext. 291 and 294).	P.O. Box 4070; Geology Bldg., Univ. of Arizona Campus.
Arkansas, Little Rock, 72201	Richard T. Sniegocki (g) (501 372–4361, ext. 270), John H. Hubble (q) (501 372–4361, ext. 219), and Ivan D. Yost (s) (501 372–4361, ext. 706).	2307, 2007, and 2301 Federal Bldg.
California, Menlo Park, 94025	Walter Hofmann (s) (415 325–6761)	345 Middlefield Rd.
Sacramento, 95814	Fred Kunkel (g) (916 449–2563) and Stanley F. Kapustka (q) (916 449–3174).	8024 and 8042 Federal Bldg. & U.S. Court House, 650 Capitol Ave.
Colorado, Denver, 80215	John W. Odell (s) (303 233–3611, ext. 6444)	Rm. 22, 1455 Ammons St.
Denver, 80225	Leonard A. Wood (g) (303 233–3611, ext. 546)	Federal Center, Bldg. 25.
Connecticut, Hartford, 06101	John Horton (s) (203 527–3281, ext. 257)	P.O. Box 715; 203 Federal Bldg.
Middletown, 06458	John A. Baker (g) (203 346–6986)	204 Post Office Bldg.
Delaware, Dover, 19901	Philip P. Fannebecker (s) (302 734–2506)	P.O. Box 707; 604 Fairview Ave.
Florida, Ocala, 32670	Kenneth A. MacKichan (q) and Archibald O. Patterson (s) (305 622–6513).	244 Federal Bldg.
Tallahassee, 32304	Clyde S. Conover (g) (305 224–1202 and 1203)	P.O. Box 2315; Gunter Bldg. (Tennessee and Woodward Sts.).

*The small letters in parentheses following each official's name signifies his affiliation in the Water Resources Division, as follows: g—Ground Water Branch; q—Quality of Water Branch; s-Surface Water Branch; w—Water Resources Division.

District Offices—Continued

Location	*Official in charge* and telephone number*	*Address*
Georgia, Atlanta, 30303	Harlan B. Counts (g) (404 688-5996)	Rm. 416, 19 Hunter St., Southwest.
Atlanta, 30323	Albert N. Cameron (s) (404 876-3311, ext. 5218).	Rm. 164, Peachtree Seventh Bldg.
Hawaii, Honolulu, 96814	Dan A. Davis (g) (588-111, ext. 694, 695) and Mearle M. Miller (s) (588-111 ext. 692, 693).	332 and 330 First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise, 83702	Wayne I. Travis (s) (208 342-2711, ext. 531) and Herbert A. Waite (g) (208 342-2711, ext. 539).	Rms. 215 and 205, 914 Jefferson St.
Illinois, Champaign, 61820	William D. Mitchell (s) (217 356-5221)	605 South Neil St.
Indiana, Indianapolis, 46204	Malcolm D. Hale (s) (317 633-7389) and Claude M. Roberts (g) (317 633-7382).	Rm. 407, 611 North Park Ave.
Iowa, Iowa City, 52241	Vernal R. Bennion (s) (319 337-9345)	508 Hydraulic Laboratory.
Iowa City, 52240	Walter L. Steinhilber (g) (319 338-1173)	Geological Survey Bldg.
Kansas, Lawrence, 66045	Robert J. Dingman (g) (913 864-3001)	c/o Univ. of Kansas.
Topeka, 66601	Edward J. Kennedy (s) (913 233-0521)	P.O. Box 856; 403 Federal Bldg.
Kentucky, Louisville, 40202	Robert V. Cushman (g) and Floyd F. Schrader (s) (502 582-5241).	310 Center Bldg., 522 West Jefferson St.
Louisiana, Baton Rouge, 70806	Mack R. Stewart (s) and Russel M. McAvoy (q) (504 924-4215).	215 and 201 Prudential Bldg., 6554 Florida Blvd.
Baton Rouge, 70803	Rex R. Meyer (g) (504 343-2873)	P.O. Box GS, University Station; 43 Atkinson Hall, Louisiana State Univ.
Maine, Augusta, 04330	Gordon S. Hayes (s) and Glenn C. Prescott (g) (207 623-4511, ext. 250).	Vickery Hill Bldg., Court St.
Maryland, Baltimore, 21218	Edmond G. Otton (g) (301 235-0771)	103 Latrobe Hall, The Johns Hopkins Univ.
College Park, 20740	William E. Forrest (s) (301 277-6270)	P.O. Box 37; 106 Engineering Classroom Bldg., Univ. of Maryland.
Rockville, 20850	John W. Wark (q) (301 762-2885)	3 Abbey Bldg., 3 North Perry St.
Massachusetts, Boston, 02110	Richard G. Peterson (g) (617 223-2822) and Charles E. Knox (s) (617 223-2824).	Rms. 206, 205, 211 Congress St.
Michigan, Lansing, 48933	Arlington D. Ash (s) (517 489-2431) and Gerth E. Hendrickson (g) (517 489-7913).	407 Capitol Savings and Loan Bldg.
Minnesota, St. Paul, 55101	David B. Anderson (s) (612 222-8011, ext. 265) and Richmond H. Brown (g) (612 222-8011, ext. 260).	1610 and 1002 New Post Office Bldg.
Mississippi, Jackson, 39205	Joe W. Lang (g) (601 354-3881, ext. 328) and William H. Robinson (s) (601 354-3881, ext. 326).	P.O. Box 2052; 302 U.S. Post Office Bldg.
Missouri, Rolla, 65401	Anthony Homyk, Jr. (s) (314 364-1599)	P.O. Box 138; 900 Pine St.
	Edward J. Harvey (g) (314 364-1752, ext 16.)	P.O. Box 138; c/o Missouri Geological Survey and Water Resources, Buehler Park.
Montana, Billings, 59601	Charles W. Lane (g) (406 259-2412)	P.O. Box 1818; Bell Bldg., 2 South 7th St. West.
Helena, 59601	Frank Stermitz (s) (406 442-4890)	P.O. Box 1696; 409 Federal Bldg.
Nebraska, Lincoln, 68508	Don M. Culbertson (q), Charles K. Keech (g), and Floyd F. Lefever (s) (402 435-3273, ext. 346, 323, and 328).	125 Nebraska Hall, 901 North 17th St.
Nevada, Carson City, 89701	George F. Worts, Jr. (w) (702 472-1388)	222 E. Washington St.
New Jersey, Trenton, 08605	John E. McCall (s) (609 394-5301, ext. 214)	P.O. Box 967; 433 Federal Bldg.
Trenton, 08607	Allen Sinnott (g) (609 394-5301, ext. 213)	P.O. Box 1238; 432 Federal Bldg.
New Mexico, Albuquerque, 87106	Samuel W. West (g) and Jay M. Stow (q) (505 247-0311, ext. 2248 and 2249).	P.O. Box 4217; Geology Bldg., Univ. of New Mexico.
Santa Fe, 87501	Wilbur L. Heckler (s) (505 982-1921)	P.O. Box 1750; Greer Bldg., 113 Washington Ave.
New York, Albany, 12201	Ralph C. Heath (g), Donald F. Dougherty (s), Felix H. Pauszek (q) (518 463-5581).	P.O. Box 948; Rms. 342, 343, 348 Federal Bldg.
North Carolina, Raleigh, 27602	Robert A. Krieger (q), Granville G. Wyrick (g), (919 828-4345), Edward B. Rice (s) (919 834-6429).	P.O. Box 2857; 4th Floor, Federal Bldg.

*See footnote p. A229.

District Offices—Continued

Location	Official in charge* and telephone number	Address
North Dakota, Bismarck, 58502	Harlan M. Erskine (s) (701 223-3525) and Delbert W. Brown (g) (701 255-0191).	P.O. Box 750; 7 and 17 Eltinge Bldg., 202½ 3d St.
Ohio, Columbus, 43212	John J. Molloy (s) (614 221-6411, ext. 113)	1509 Hess St.
Columbus, 43209	George W. Whetstone (q) (614 221-6411, ext. 118)	554 U.S. Post Office Bldg.; 2822 East Main St.
Columbus, 43215	Stanley E. Norris (g) (614-221-6411, ext. 281)	85 Marconi Blvd.
Oklahoma, Oklahoma City, 73102	Alvin R. Leonard (g) 405 236-2311, ext. 412) and Alexander A. Fischback, Jr. (s) (405 236-2311, ext. 257).	4011 and 4301 Federal Bldg., 200 Northwest 4th St.
Oklahoma City, 73109	Richard P. Orth (q) (405 677-5022)	P.O. Box 4355; 2800 South Eastern.
Oregon, Portland, 97208	Roy B. Sanderson (s) and Eugene R. Hampton (g) (503 226-3361, ext. 1246, 1248).	P.O. Box 3418; 415 and 419 Old Post Office Bldg., 511 NW. Broadway.
	Leslie B. Laird (q) (503 234-3361, ext. 241)	P.O. Box 3202; 416 Old Post Office Bldg., 511 NW. Broadway.
Pennsylvania, Harrisburg, 17104	Joseph E. Barcley (g) (717 238-4925)	100 North Cameron St.
	Robert E. Steacy (s) (717 787-3305)	1224 Mulberry St.
Philadelphia, 19106	Norman H. Beamer (q) (215 627-6000, ext. 274)	1302 U.S. Custom House, 2d and Chestnut Sts.
Puerto Rico, Hato Rey, 00918	Dean B. Bogart (w) (766-3310)	12 Arroyo St.
Rhode Island, Providence, 02903	William B. Allen (g) (401 331-9312)	401-2 Federal Bldg. and U.S. Post Office.
South Carolina, Columbia, 29201	Albert E. Johnson (s) (803 252-2449)	121 Veterans Administration Regional Office Bldg., 1801 Assembly St.
Columbia, 29205	George E. Siple (g) (803 253-7478)	P.O. Box 5314; 627 Bull St.
South Dakota, Huron, 57350	John E. Powell (g) (605 352-8584)	P.O. Box 1412; 231 Federal Bldg.
Pierre, 57501	John E. Wagar (s) (605 224-7856)	P.O. Box 216; 207 Federal Bldg.
Tennessee, Chattanooga, 37402	Joseph S. Cragwall, Jr. (w) (615 266-2725)	823 Edney Bldg.
Texas, Austin, 78701	Charles H. Hembree (q), Allen G. Winslow (g), and Trigg Twichell (s) (512 476-6411).	Vaughn Bldg., 807 Brazos St.
Utah, Salt Lake City, 84111	Russell H. Langford (q) (801 524-5661 and 5622), Ted Arnow (g) (801 524-5654 and 5655), and Milton T. Wilson (s) (801 524-5663, 5664, and 5665).	305, 125 and 130 Empire Bldg., 231 East 4th South.
Virginia, Charlottesville, 22903	James W. Gambrell (s) (703 293-2127)	P.O. Box 3327, University Station; Natural Resources Bldg., McCormick Rd.
Washington, Tacoma, 98409	Arthur A. Garrett (g) (206 474-4261)	3020 South 38th St.
	Fred M. Veatch (s) (206 383-1491)	207 Federal Bldg.
West Virginia, Charleston, 25301	William C. Griffin (s) (304 343-6181, ext. 311)	3303 New Federal Office Bldg., 500 Quarrier St. East.
Morgantown, 26506	Porter E. Ward (g) (304 542-8103)	405 Mineral Industries Bldg., Univ. of West Virginia.
Wisconsin, Madison, 53706	Charles R. Holt, Jr. (g) (608 262-2488)	175 Science Hall, Univ. of Wisconsin.
Madison, 53705	Kenneth B. Young (s) (608 233-0195)	5001 University Ave.
Wyoming, Cheyenne, 82002	Ellis D. Gordon (g) and Leon A. Wiard (s) (307 634-2731, ext. 37 and 23).	P.O. Box 177, Frangos Bldg., 2123 Carey Ave.
Worland, 82401	Thomas F. Hanley (q) (307 347-2181)	1214 Big Horn Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	Official in charge	Address
Bolivia, La Paz	Charles M. Tschanz	U.S. Geological Survey, U.S. AID/Bolivia, c/o American Embassy, La Paz, Bolivia.

*See footnote, p. A229.

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Location	Official in charge	Address
Brazil, Rio de Janeiro	Alfred J. Bodenlos	U.S. Geological Survey, U.S. AID/ Rio, APO 676, New York, N.Y.
Colombia, Bogotá	Earl M. Irving	U.S. Geological Survey, U.S. AID/ American Embassy, Bogotá, Colombia.
Dahomey, Cotonou	Jules A. MacKallor	U.S. Geological Survey, U.S. AID/ Cotonou, U.S. Department of State, Washington, D.C. 20523.
Germany, Heidelberg	Jerald M. Goldberg	U.S. Geological Survey Team Representative (Europe), USAREUR Engineer Intelligence Center, APO 403, New York, N.Y.
Indonesia, Bandung	Reed J. Anderson	U.S. Geological Survey, U.S. AID/ American Embassy, APO 156, San Francisco, Calif.
Liberia, Monrovia	Darwin L. Rossman	U.S. Geological Survey, U.S. AID/ Monrovia, U.S. Department of State, Washington, D.C. 20523.
Pakistan, Quetta	Max G. White	U.S. Geological Survey, U.S. AID/ American Embassy, APO 271 New York, N.Y.
Philippines, Manila	Joseph F. Harrington	U.S. Geological Survey, c/o American Embassy, APO 928, San Francisco, Calif.
Saudi Arabia, Jidda	Glen F. Brown	U.S. Geological Survey, c/o American Embassy, APO 697, New York, N.Y.
Thailand, Bangkok	Charles T. Pierson	U.S. Geological Survey/UN, c/o American Embassy, APO 146, San Francisco, Calif.

WATER RESOURCES DIVISION

Location	Official in charge	Address
Afghanistan, Kabul	Arthur O. Westfall	U.S. Geological Survey, U.S. AID/ Kabul, U.S. Department of State, Washington, D.C. 20523.
Brazil, Recife	Stuart L. Schoff (g) and Leonard J. Snell (s)	U.S. Geological Survey, U.S. AID/ Brazil (Recife), APO 676, New York, N.Y.
Nepal, Katmandu	Woodrow W. Evett	U.S. Geological Survey, U.S. AID/N (Box KAT), APO 959, San Francisco, Calif.
Nigeria, Kaduna	David A. Phoenix	U.S. Geological Survey, U.S. AID/ Lagos (Kaduna), U.S. Department of State, Washington, D.C. 20523.
Pakistan, Lahore	Maurice J. Mundorff	U.S. Geological Survey, U.S. AID/ Pakistan, APO 271, New York, N.Y.
Tunisia, Tunis	Vinton C. Fishel	U.S. Geological Survey, c/o U.S. AID/Tunis, U.S. Dept. of State, Washington, D.C. 20523.
Turkey, Ankara	C. Richard Murray	U.S. Geological Survey, U.S. Economic Coordinator/Ankara, APO 254, New York, N.Y.
United Arab Republic, Egypt, Cairo	Robert L. Cushman	U.S. Geological Survey, U.S. AID/ Cairo, U.S. Dept. of State, Washington, D.C. 20523.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC, WATER RESOURCES, AND CONSERVATION DIVISIONS

Investigations in progress during fiscal year 1964 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (W) for Washington, D.C., (D) for Denver, Colo., and (M) for Menlo Park, Calif. Headquarters in other cities are indicated by name; see list of offices (p. A227) for addresses. Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C. 20242. Lowercase letter following the name of the project leader shows the division technical responsibility: c, Conservation Division; w, Water Resources Division (g, Ground Water Branch; s, Surface Water Branch; q, Quality of Water Branch; h, General Hydrology Branch); no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under Geologic Mapping unless a special topic or commodity are the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading Geologic Mapping for projects in areas of volcanic rocks, as well as under the heading Volcanology. Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under Water Resources unless the special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (1:62,500; 1:24,000).

Analytical chemistry:
- Analytical methods—water chemistry (M. W. Skougstad, q, D)
- Analytical services and research (I. May, W; L. F. Rader, Jr., D; R. E. Stevens, M)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances in water (W. L. Lamar, q, M)
- Physical chemistry of radioelements (K. W. Edwards, q, D)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - general (L. C. Peck, D)
  - rapid (L. Shapiro W)
- Trace analysis methods:
  - development (H. W. Lakin, D)
  - research (F. N. Ward, D)
- Trace analysis service (F. N. Ward, D)
- *See also* Spectroscopy.

Artificial recharge:
- Basalt aquifers, Salem Heights, Oreg. (B. L. Foxworthy, g, Portland)
- Basalt aquifers, The Dalles, Oreg. (B. L. Foxworthy, g, Portland)
- Experimental recharge basin—surface water (R. M. Sawyer, s, Albany, N.Y.)
- Grand Prairie region, Arkansas (R. T. Sniegocki, g, Little Rock)

Artificial recharge—Continued
- High Plains, N. Mex. (J. S. Havens, g, Albuquerque)
- Kalamazoo, Mich. (J. E. Reed, g, Lansing)
- Water application and use on a range water spreader, northeast Montana (F. A. Branson, w, D)

Asbestos:
- Arizona, McFadden Peak and Blue House quadrangles (A. F. Shride, D)
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)
- Vermont, north-central (W. M. Cady, D)

Barite:
- Arkansas (D. A. Brobst, D)

Base metals:
- Colorado:
  - Tenmile Range and Kokomo mining district (M. H. Bergendahl, D)
  - Wet Mountains (M. R. Brock, D)
- Montana, Philipsburg area (W. C. Prinz, W)
- Nevada, Antler Peak quadrangle (R. J. Roberts, M)
- Utah, San Francisco Mountains (D. M. Lemmon, M)
- *See also base-metal names.*

Bauxite:
- Hawaii, Kauai (S. H. Patterson, W)
- Southeastern United States (E. F. Overstreet, W)

Beryllium:
- Alaska, Lost River mining district (C. L. Sainsbury, D)

Contamination, water—Continued
- Ground-water contamination (H. E. LeGrand, g, W)
- Sewage lagoon study (W. J. Powell, g, Tuscaloosa, Ala.)
- *See also* Detergents, Radioactive-waste disposal.

Copper:
- Massive sufide deposits (A. R. Kinkel, Jr., W)
- Sandstone copper deposits, Southwest United States (C. B. Read, Albuquerque, N. Mex.)
- Alaska, southern Brooks Range (W. P. Brosgé, M)
- Arizona:
  - Benson and Mammoth quadrangles (S. C. Creasey, M)
  - Globe-Miami area (D. W. Peterson, M)
  - Klondyke quadrangle (F. G. Simons, D)
  - Little Dragoons area (J. R. Cooper, D)
  - Lochiel and Nogales quadrangles (F. S. Simons, D)
  - Twin Buttes area (J. R. Cooper, D)
- Colorado, Lisbon Valley area (G. W. Weir, Berea, Ky.)
- Michigan, Michigan copper district (W. S. White, W)
- Nevada, Ely district (A. L. Brokaw, D)
- New Mexico, Silver City region (W. R. Jones, D)
- Tennessee, Ducktown district and adjacent areas (R. M. Hernon, D)
- Utah:
  - Bingham Canyon district (R. J. Roberts, M)
  - Lisbon Valley area (G. W. Weir, Berea, Ky.)
  - White Canyon area (R. E. Thaden, Columbia, Ky.)

Crustal studies. *See* Geophysics, regional.

Crystallography. *See* Mineralogy and crystallography.

Detergents:
- Behavior of detergents and other pollutants in soil-water environments (C. H. Wayman, h, D)
- Detergent contamination in three public-supply well fields, Suffolk County, N.Y. (N. M. Perlmutter, g, Albany)

Engineering geologic studies. *See* Construction and terrain problems; Urban geology.

Evaporation:
- Evaporation from Lake Helene, Fla. (R. B. Stone, s, Ocala)
- Pond-evaporation study (F. N. Lee, s, Baton Rouge, La.)
- Reservoir evaporation, San Diego County, Calif. (W. Hofmann, s, M)

Evaporation suppression (G. E. Koberg, h, D)

Evapotranspiration:
- Effect of removing riprian vegetation, Cottonwood Wash, Ariz. (J. E. Bowie, w, Tucson)
- Evapotranspiration measurements, Deep Creek, Tex. (F. W. Kennon, s, Austin)
- Evapotranspiration theory and measurement (O. E. Leppanen, h, Phoenix, Ariz.)
- Hydrologic effects of vegetation modification (R. M. Myrick, h, Tucson, Ariz.)
- Phreatophyte study, Gila River, Ariz. (R. C. Culler, h, Tucson)
- Use of water by saltcedar in evapotranspirometers compared with energy-budget and mass-transfer computations (T. E. A. Van Hylckama, h, Tucson, Ariz.)

Extraterrestrial studies:
- Astronauts, geologic-training program (R. E. Eggleton, Flagstaff, Ariz.)

Extraterrestrial studies—Continued
- Cratering, impact, and thermal investigations:
  - Experimental hypervelocity impact studies (H. J. Moore, M)
  - Impact metamorphism (E. C. T. Chao, W)
  - Shock-phase studies (D. J. Milton, M)
  - Tension fractures and thermal investigations (A. H. Lachenbruch, M)
  - Terrestrial impact structures (E. M. Shoemaker, Flagstaff, Ariz.)
  - Thermoluminescence and mass physical properties (C. H. Roach, D)
- Lunar experiments:
  - Lunar physical properties, measuring techniques (E. M. Shoemaker, Flagstaff, Ariz.)
  - X-ray fluorescence equipment for lunar studies (I. Adler, W)
- Lunar mapping:
  - Lunar stratigraphy and structure (R. J. Hackman, W; H. Masursky, M)
  - Lunar photometry (W. A. Fischer, W)
  - Lunar-terrain studies (C. R. Warren, W)
- Tektite and meteorite investigations:
  - Magnetic properties of tektites (A. N. Thorpe, W)
  - Chemistry of tektites (F. Cuttita, W)
  - Mineralogy and petrology of meteorites and tektites (E. C. T. Chao, W)

Ferro-alloy metals:
- Molybdenum-rhenium resource studies (R. U. King, D)
- Manganese, geology and geochemistry (D. F. Hewett, M)
- Ultramafic rocks of the Southeastern United States (D. M. Larrabee, W)
- California:
  - Chromite deposits, northern California (F. G. Wells, W)
  - Nickel deposits, Klamath Mountains (P. E. Hotz, M)
  - Tungsten, Bishop district (P. C. Bateman, M)
- Idaho, Blackbird Mountain area (J. S. Vhay, Spokane, Wash.)
- Montana:
  - Chromite resources and petrology, Stillwater complex (E. D. Jackson, Houston, Tex.)
  - Manganese deposits, Philipsburg area (W. C. Prinz, W)
- Oregon:
  - John Day area (T. P. Thayer, W)
  - Nickel deposits, Klamath Mountains (P. E. Hotz, M)
- Utah, San Francisco Mountains (D. M. Lemmon, M)

Flood characteristics of streams at selected sites:
- Alabama (C. O. Ming, s, Tuscaloosa)
- Florida (W. C. Bridges, s, Ocala)
- Georgia (C. M. Bunch, s, Atlanta)
- Illinois (W. D. Mitchell, s, Champaign)
- Kentucky (C. H. Hannum, s, Louisville)
- Mississippi (K. V. Wilson, and C. Humphreys, Jr., s, Jackson)
- Nebraska (E. W. Beckman, s, Lincoln)
- Puerto Rico (I. J. Hickenlooper, w, San Juan)
- Tennessee (W. J. Randolph, w, Chattanooga)
- Wyoming (J. R. Carter, s, Cheyenne)

Geologic mapping—Continued
- Map scale smaller than 1 inch to 1 mile—Continued
  - Alaska—Continued
    - Lower Yukon–Koyukuk area (W. W. Patton, Jr., M)
    - Lower Yukon–Norton Sound region (J. M. Hoare, M)
    - Nelchina area (A. Grantz, M)
    - Northern Alaska, petroleum investigations (G. Gryc, M)
    - Southeastern Alaska, regional geology and mineral resources (R. A. Loney, M)
    - Southern Brooks Range (W. P. Brosgé, M)
    - Yukon-Koyukuk lowland, engineering geology (F. R. Weber, College)
  - Antarctica:
    - Eights and Walgreen coasts, reconnaissance geology (A. A. Drake, Jr., W)
    - Western Antarctica, reconnaissance geology (E. L. Boudette, W)
  - Colorado:
    - Grand Junction 2-degree quadrangle (W. B. Cashion, D)
    - Oil-shale investigations (D. C. Duncan, W)
  - Idaho:
    - Central Snake River plain, volcanic petrology (H. A. Powers, D)
    - Mackay quadrangle (C. P. Ross, D)
    - Spokane-Wallace region (A. B. Griggs, M)
  - Montana, Spokane-Wallace region (A. B. Griggs, M)
  - Nevada:
    - Clark County (C. R. Longwell, M)
    - Esmeralda County (J. P. Albers, M)
    - Eureka County (R. J. Roberts, M)
    - Humboldt County (C. R. Willden, D)
    - Lincoln County (C. M. Tschanz, La Paz, Bolivia)
    - Lyon, Douglas, and Ormsby Counties (J. G. Moore, Hilo, Hawaii)
    - Nevada Test Site, reconnaissance (F. N. Houser, D)
    - Nye County, northern part (F. J. Kleinhampl, M)
    - Nye County, southern part (H. R. Cornwall, M)
    - Pershing County (D. B. Tatlock, M)
    - Ruby Mountains (C. R. Willden, D)
    - White Pine County (R. K. Hose, M)
  - New Mexico, geologic map (C. H. Dane, W)
  - Oregon, geologic map (G. W. Walker, M)
  - Utah, Grand Junction 2-degree quadrangle (W. B. Cashion, D)
  - Washington:
    - Grays Harbor basin, regional compilation (H. M. Beikman, M)
    - Spokane-Wallace region (A. B. Griggs, M)
- Map scale 1 inch to 1 mile, and larger:
  - Alabama, Warrior quadrangle (W. C. Culbertson, D)
  - Alaska:
    - Aleutian Islands, eastern (R. E. Wilcox, D)
    - Aleutian Islands, western (R. E. Wilcox, D)
    - Aleutian Trench–Trinity Island (G. W. Moore, M)

Geologic mapping—Continued
- Map scale 1 inch to 1 mile, and larger—Continued
  - Alaska—Continued
    - Anchorage–Matanuska Glacier area, surficial geology (T. N. V. Karlstrom, W)
    - Beluga-Yentna area (F. F. Barnes, M)
    - Bering River coal field (A. A. Wanek, c, Anchorage)
    - Copper River Basin, northeastern, surficial geology (O. J. Ferrians, Jr., W)
    - Copper River Basin, southeastern, surficial geology (D. R. Nichols, W)
    - Copper River Basin, southwestern, surficial geology (J. R. Williams, W)
    - Eastern Denali Highway, surficial geology (D. R. Nichols, W)
    - Gulf of Alaska Tertiary province (G. Plafker, M)
    - Heceta-Tuxekan area (G. D. Eberlein, M)
    - Iniskin-Tuxedni region (R. L. Detterman, M)
    - Johnson River district, surficial geology (H. L. Foster, W)
    - Katmai National Monument, petrology and volcanism (G. H. Curtis, M)
    - Lost River mining district (C. L. Sainsbury, D)
    - Lower Chitina Valley, surficial geology (L. A. Yehle, W)
    - Mt. Chamberlain area, surficial geology (C. R. Lewis, W)
    - Mt. Hayes D–3 and D–4 quadrangles (T. L. Péwé, College)
    - Mount Michelson area (E. G. Sable, Elizabethtown, Ky.)
    - Nenana coal investigations (C. Wahrhaftig, M)
    - Nome C–1 and D–1 quadrangles (C. L. Hummel, Bangkok, Thailand)
    - Northeastern Alaska coastal plain and foothills (C. R. Lewis, W)
    - Project CHARIOT (harbor construction) (C. D. Eberlein, M)
    - Seward-Portage Railroad, surficial geology (T. N. V. Karlstrom, W)
    - Slana-Tok area, surficial geology (H. R. Schmoll, W)
    - Steese Highway area, surficial geology (W. E. Davies, W)
    - Taylor Highway area, surficial geology (H. L. Foster, W)
    - Tofty placer district (D. M. Hopkins, M)
    - Upper Tanana River, surficial geology (A. T. Fernald, W)
    - Valdez-Tiekel belt, surficial geology (H. W. Coulter, W)
    - Windy-Curry area (R. Kachadoorian, M)
  - Antarctica:
    - Horlick Mountains (A. B. Ford, W)
    - Pensacola Mountains (A. B. Ford, W)
    - Wrangell Mountains, southern (E. M. MacKevett, Jr., M)
  - Arizona:
    - Bradshaw Mountains (C. A. Anderson, W)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Arizona—Continued
Carrizo Mountains area (J. D. Strobell, D)
Christmas quadrangle (C. R. Willden, D)
Cibecue-Grasshopper area (T. L. Finnell, D)
Cochise County, southern part (P. T. Hayes, D)
Elgin quadrangle (R. B. Raup, D)
Gila River basin, upper part (R. B. Morrison, D)
Globe-Miami area (D. W. Peterson, M)
Heber quadrangle (E. J. McKay, D)
Holy Joe Peak quadrangle (M. H. Krieger, M)
Klondyke quadrangle (F. S. Simons, D)
Little Dragoons area (J. R. Cooper, D)
Lochiel and Nogales quadrangles (F. S. Simons, D)
McFadden Peak and Blue House Mountain quadrangles (A. F. Shride, D)
Mammoth and Benson quadrangles (S. C. Creasey, M)
Mount Wrightson quadrangle (H. Drewes, D)
Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
Prescott-Paulden area (M. H. Krieger, M)
Show Low quadrangle (E. J. McKay, D)
Twin Buttes area (J. R. Cooper, D)
Winkelman quadrangle (M. H. Krieger, M)
Arkansas:
Arkansas Basin, coal investigations (B. R. Haley, D)
Ft. Smith district (T. A. Hendricks, D)
Malvern quadrangle (W. Danilchik, Santiago, Chile)
Northern Arkansas, oil and gas investigations (E. E. Glick, D)
California:
Ash Meadows quadrangle (C. S. Denny, W)
Beatty area (H. R. Cornwall, M)
Big Maria, Little Maria, and Riverside Mountains (W. B. Hamilton, D)
Bishop tungsten district (P. C. Bateman, M)
Blanco Mountain quadrangle (C. A. Nelson, Los Angeles)
Burney area (G. A. Macdonald, Honolulu, Hawaii)
Coast Range ultramafic rocks (E. H. Bailey, M)
Condrey Mountain quadrangle (P. E. Hotz, M)
Cuyama Valley area (J. G. Vedder, M)
Death Valley (C. B. Hunt, Baltimore, Md.)
Furnace Creek area (J. F. McAllister, M)
Independence quadrangle (D. C. Ross, M)
Klamath Mountains, southern part (W. P. Irwin, M)
Los Angeles area (J. T. McGill, Los Angeles)
Los Angeles basin, eastern part (J. E. Schoellhamer, W)
Malibu Beach quadrangle (R. F. Yerkes, M)
Merced Peak quadrangle (D. L. Peck, Hawaii)
Mojave Desert, south-central (T. W. Dibblee, Jr., M)
Mojave Desert, western (T. W. Dibblee, Jr., M)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
California—Continued
Mt. Diablo area (E. H. Pampeyan, M)
New York Butte quadrangle (W. C. Smith, M)
Oakland East quadrangle (D. H. Radbruch, M)
Palo Alto quadrangle (E. H. Pampeyan, M)
Panamint Butte quadrangle (W. E. Hall, W)
Point Dume quadrangle (R. H. Campbell, M)
Priest Valley SW quadrangle (E. E. Richardson, c, Taft)
Sacramento Valley, northwest part (R. D. Brown, Jr., M)
Salinas Valley (D. L. Durham, M)
San Andreas fault (L. F. Noble, Valyermo)
San Francisco North quadrangle (J. Schlocker, M)
San Francisco South quadrangle (M. G. Bonilla, M)
San Mateo quadrangle (G. O. Gates, M)
Searles Lake area (G. I. Smith, M)
Shuteye Peak area (N. K. Huber, M)
Sierra foothills mineral belt (L. D. Clark, M)
Sierra Nevada batholith (P. C. Bateman, M)
Sierra tungsten belt, eastern (N. K. Huber, M)
Colorado:
Air Force Academy (D. J. Varnes, D)
Animas River area (H. Barnes, D)
Anthracite NE and NW, and Snowmass SW quadrangles (D. L. Gaskill, c, D)
Aspen quadrangle (B. Bryant, D)
Baggs area (G. E. Prichard, D)
Berthoud Pass quadrangle (P. K. Theobald, D)
Black Canyon of the Gunnison River (W. R. Hansen, D)
Bottle Pass and Black Hawk quadrangles (R. B. Taylor, D)
Boulder quadrangle (C. T. Wrucke, D)
Bull Canyon district (C. H. Roach, D)
Cameron Mountain quadrangle (M. G. Dings, D)
Carbondale coal field (J. R. Donnell, D)
Cheyenne Mountain, electrical properties (J. H. Scott, D)
Creede district (T. A. Steven, D)
Denver metropolitan area (R. M. Lindvall, D)
Eldorado Springs quadrangle (J. D. Wells, D)
Elk Springs quadrangle (J. R. Dyni, c, D)
Empire quadrangle (W. A. Braddock, D)
Fort Lupton, Hudson, Platteville, Hanover NW and Carrol Bluffs quadrangles (P. E. Soister, c, D)
Fraser and East Portal quadrangles (O. L. Tweto, D)
Front Range, Fort Collins area (W. A. Braddock, D)
Golden quadrangle (R. Van Horn, D)
Grand-Battlement Mesa (J. R. Donnell, D)
Green River Valley, upper part (W. R. Hansen, D)
Holy Cross quadrangle (O. Tweto, D)

Geologic mapping—Continued
- Map scale 1 inch to 1 mile, and larger—Continued
  - Colorado—Continued
    - Hot Sulphur Springs and Kremmling quadrangles (G. A. Izett, c, D)
    - La Sal area (W. D. Carter, W)
    - Lafayette quadrangle (K. B. Ketner, D)
    - Lake George district (C. C. Hawley, D)
    - Lisbon Valley area (G. W. Weir, Berea, Ky.)
    - Maybell-Lay area (M. J. Bergin, W)
    - Morrison quadrangle (J. H. Smith, D)
    - Montrose 1 SW, 1 SE, 4 NE and Cerro Summit quadrangles (R. G. Dickinson, c, D)
    - Mt. Antero (W. N. Sharp, D)
    - Mt. Harvard quadrangle (M. R. Brock, D)
    - Mountain front area, east-central Front Range (D. M. Sheridan, D)
    - Nederland and Tungsten quadrangles (D. J. Gable, D)
    - North Park, eastern (D. M. Kinney, W)
    - North Park, western (W. J. Hail, D)
    - Placita, SE quadrangle (L. D. Godwin, c, D)
    - Poncha Springs and Bonanza quadrangles (R. E. Alstine, W)
    - Powderhorn area (J. C. Olson, D)
    - Pueblo and vicinity (G. R. Scott, D)
    - Ralston Buttes (D. M. Sheridan, D)
    - Rico-Animas area (W. P. Pratt, D)
    - Rico district (E. T. McKnight, W)
    - San Juan mining area (R. G. Luedke, W)
    - San Juan Mountains, western (A. L. Bush, D)
    - Slick Rock district (D. R. Shawe, D)
    - South Platte River, upper part (G. R. Scott, D)
    - Squaw Pass, Evergreen, and Indian Hills quadrangles (D. M. Sheridan, D)
    - Straight Creek tunnel (C. S. Robinson, D)
    - Tenmile Range and Kokomo mining district (M. H. Bergendahl, D)
    - Thornburg area (J. R. Dyni, c, D)
    - Trinidad coal field (R. B. Johnson, D)
    - Ute Mountains (E. B. Ekren, D)
    - Wet Mountains (M. R. Brock, D)
  - Connecticut:
    - Ansonia and Milford quadrangles—bedrock (C. E. Fritts, D)
    - Ashaway and Voluntown quadrangles—bedrock (T. G. Feininger, Boston, Mass.)
    - Ashaway and Watch Hill quadrangles—surficial (J. P. Schafer, Boston, Mass.)
    - Ashley Falls and Tolland Center quadrangles—materials mapping (G. W. Holmes, M)
    - Bristol and New Britain quadrangles—bedrock (H. E. Simpson, D)
    - Broad Brook and Manchester quadrangles (R. B. Colton, W)
    - Columbia, Fitchville, and Marlborough quadrangles—bedrock (G. L. Snyder, D)
    - Danielson, Hampton, Plainfield, and Scotland quadrangles—bedrock (H. R. Dixon, Boston, Mass.)

Geologic mapping—Continued
- Map scale 1 inch to 1 mile, and larger—Continued
  - Connecticut—Continued
    - Durham quadrangle (H. E. Simpson, D)
    - Meriden quadrangle—bedrock (P. M. Hanshaw, Boston, Mass.)
    - Montville, Mystic, and Uncasville quadrangles—bedrock (R. Goldsmith, Boston, Mass.)
    - New Hartford quadrangle (R. W. Schnabel, D)
    - New London, Niantic, and Old Mystic quadrangles (R. Goldsmith, D)
    - Southwick quadrangle (R. W. Schnabel, D)
    - Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston, Mass.)
    - Taconic sequence (E. Zen, W)
    - Tarriffville quadrangle—surficial (A. D. Randall, g, Middletown)
    - Tarriffville and Windsor Locks quadrangles—bedrock (R. W. Schnabel, D)
    - Thompson quadrangle (P. M. Hanshaw, H. R. Dixon, Boston, Mass.)
    - Watch Hill quadrangle—bedrock (G. E. Moore, Jr., Columbus, Ohio)
    - West Springfield quadrangle (R. B. Colton, J. H. Hartshorn, Boston, Mass.)
  - District of Columbia, Washington metropolitan area (H. W. Coulter and C. F. Withington, W)
  - Florida:
    - Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, W)
    - Land-pebble phosphate deposits (J. B. Cathcart, D)
  - Georgia, Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, W)
  - Greenland, Schuchert Dal, East Greenland, glacial geology (J. S. Hartshorn, Boston, Mass.)
  - Idaho:
    - American Falls region (D. E. Trimble, D)
    - Aspen Range–Dry Ridge area (V. E. McKelvey, W)
    - Bancroft quadrangle (S. S. Oriel, D)
    - Bayhorse area (S. W. Hobbs, D)
    - Big Creek quadrangle (B. F. Leonard, D)
    - Blackbird Mountain area (J. S. Vhay, Spokane, Wash.)
    - Central Idaho, radioactive placer deposits (D. L. Schmidt, W)
    - Clarks Fork and Packsaddle Mountain quadrangles (J. E. Harrison, W)
    - Coeur d' Alene mining district (S. W. Hobbs, D)
    - Doublesprings quadrangle (W. J. Mapel, D)
    - Driggs quadrangle (E. H. Pampeyan, c, D)
    - Garns Mountain quadrangle (M. H. Staatz, c, D)
    - Greenacres quadrangle (P. L. Weis, Spokane, Wash.)
    - Hawley Mountain quadrangle (W. J. Mapel, D)
    - Irwin 1, 2, 4NE, and 4 NW quadrangles (D. A. Jobin, c, D)
    - Leadore and Patterson quadrangles (E. T. Ruppel, D)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Idaho—Continued
Morrison Lake quadrangle (E. R. Cressman, Lexington, Ky.)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Orofino area (A. Hietanen-Makela, M)
Owyhee and Mountain City quadrangles (R. R. Coats, M)
Pocatello quadrangle (D. E. Trimble, D)
Riggins quadrangle (W. B. Hamilton, D)
Soda Springs quadrangle (F. C. Armstrong, D)
Upper Valley quadrangle (R. L. Rioux, c, D)
Yellow Pine quadrangle (B. F. Leonard, D)
Illinois, Wisconsin zinc-lead mining district (J. W. Whitlow, W)
Indiana, Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Iowa, Omaha-Council Bluffs and vicinity (R. D. Miller, D)
Kansas:
Shawnee County (W. D. Johnson, Jr., Lawrence)
Wilson County (H. C. Wagner, M)
Kentucky:
Note: The entire State of Kentucky is being mapped geologically by 7½-minute quadrangles under a cooperative program with the Kentucky Geological Survey; 91 quadrangles have been published and 227 more are currently in progress. Project is under the supervision of P. W. Richards, Lexington, Ky. The following investigations are separate from the cooperative mapping program:

Eastern Kentucky coal investigations (K. J. Englund, W)
Jellico West and Ketchen quadrangles, Tennessee and Kentucky (K. J. Englund, W)
Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Southern Appalachian folded belt (L. D. Harris, W)
Maine:
Aroostook County, southern (L. Pavlides, W)
Attean quadrangle (A. L. Albee, Pasadena, Calif.)
Big Lake area (D. M. Larrabee, W)
Greenville quadrangle (G. H. Espenshade, W)
Kennebago Lake quadrangle (E. L. Boudette, W)
Moosehead gabbro (G. H. Espenshade, W)
Paleozoic stratigraphy, regional (R. B. Neuman, W)
Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
The Forks quadrangle (F. C. Canney, E. V. Post, D)
Maryland:
Allegany County (W. de Witt, Jr., W)
Harford County (D. Southwick, W)
Washington, D.C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Massachusetts:
Assawompsett Pond quadrangle (C. Koteff, Boston)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Massachusetts—Continued
Athol quadrangle (D. F. Eschman, Ann Arbor, Mich.)
Billerica, Lowell, Tyngsboro, and Westford quadrangles (R. H. Jahns, University Park, Pa.)
Blue Hills quadrangle (N. E. Chute, Syracuse, N.Y.)
Boston and vicinity (C. A. Kaye, Boston, Mass.)
Clinton and Shrewsbury quadrangles, bedrock (R. F. Novotny, Boston)
Concord quadrangle (N. P. Cuppels, C. Koteff, Boston)
Duxbury and Scituate quadrangles (N. E. Chute, Syracuse, N.Y.)
Georgetown quadrangle (N. P. Cuppels, Boston)
Lawrence, Reading, South Groveland, and Wilmington quadrangles—bedrock (R. O. Castle, Los Angeles, Calif.)
Norwood quadrangle (N. E. Chute, Syracuse, N.Y.)
Plainfield quadrangle—bedrock (P. H. Osberg, Orono, Maine)
Reading and Salem quadrangles—surficial geology (R. N. Oldale, Boston)
Rowe and Heath quadrangles (A. H. Chidester, D; J. H. Hartshorn, Boston)
Salem quadrangle—bedrock (P. Toulmin III, W)
Southwick quadrangle (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston)
Taconic sequence (E. Zen, W)
Taunton quadrangle (J. H. Hartshorn, Boston)
West Springfield quadrangle (R. B. Colton, D; J. H. Hartshorn, Boston)
Michigan:
Dickinson County, southern (R. W. Bayley, M)
Cogebic Range, eastern (W. C. Prinz, W)
Iron County, eastern (K. L. Wier, D)
Iron River–Crystal Falls district (H. L. James, Minneapolis, Minn.)
Lake Algonquin drainage (J. T. Hack, W)
Marquette district, eastern (J. E. Gair, D)
Michigan copper district (W. S. White, W)
Negaunee and Palmer quadrangles (J. E. Gair, D)
Mississippi, Tatum salt dome (W. S. Twenhofel, D)
Missouri, southeastern lead deposits (T. H. Kiilsgaard, W)
Montana:
Alberton quadrangle (J. D. Wells, W)
Anaconda 3 NW quadrangle (A. A. Wanek, c, D)
Bearpaw Mountains, petrology (W. T. Pecora, W)
Black Butte and Hedstrom quadrangles (A. W. Bateman, c, Great Falls)
Boulder batholith area (M. R. Klepper, W)
Browning area, Quaternary geology (G. M. Richmond, D)
Clarks Fork and Packsaddle Mountain quadrangles (J. E. Harrison, W)
Crazy Mountains Basin (B. A. Skipp, D)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Montana—Continued
Divide 2 SW quadrangle (G. D. Fraser, c, D)
Gardiner SW quadrangle (G. D. Fraser, c, D)
Girard coal field (G. E. Prichard, D)
Great Falls area (R. W. Lemke, D)
Holter Lake quadrangle (G. D. Robinson, D)
Hughesville quadrangle (I. J. Witkind, D)
Jordan quadrangle (G. D. Mowat, c, Great Falls)
Livingston–Trail Creek area (A. E. Roberts, D)
Maudlow quadrangle (B. A. Skipp, D)
Montaqua quadrangle (E. D. Patterson, c, W)
Morrison Lake quadrangle (E. R. Cressman, Lexington, Ky.)
Neihart 1 quadrangle (W. R. Keefer, D)
Philipsburg area, manganese deposits (W. C. Prinz, W)
Powder River coal fields (N. W. Bass, D)
Rocky Reef and Hardy quadrangles (K. S. Soward, c, Great Falls)
Southwestern part, ore deposits (K. L. Wier, D)
Sun River Canyon area (M. R. Mudge, D)
Tepee Creek quadrangle (I. J. Witkind, D)
Toston quadrangle (G. D. Robinson, D)
Varney and Cameron quadrangles (J. B. Hadley, W)
Willis quadrangle (W. B. Myers, D)
Wolf Creek area, petrology (R. G. Schmidt, W)
Wolf Point area (R. B. Colton, D)
Nebraska:
Franklin, Webster, and Nuckolls Counties (R. D. Miller, D)
Omaha–Council Bluffs and vicinity (R. D. Miller, D)
Valley County (R. D. Miller, D)
Nevada:
Antler Peak quadrangle (R. J. Roberts, M)
Ash Meadows quadrangle (C. S. Denny, W)
Beatty area (H. R. Cornwall, M)
Cortez quadrangle (J. Gilluly, D)
Ely district (A. L. Brokaw, D)
Eureka, Pinto Summit, and Bellevue Peak quadrangles (T. B. Nolan, W)
Frenchie Creek quadrangle (L. J. P. Muffler, M)
Horse Creek Valley quadrangle (H. Masursky, M)
Humboldt Range, Unionville and Buffalo Mountain quadrangles (R. E. Wallace, M)
Jiggs quadrangle (C. R. Willden, D)
Kobeh Valley (T. B. Nolan, W; C. W. Merriam, M)
Las Vegas–Lake Mead area (C. R. Longwell, M)
Montello area (R. G. Wayland, c, Los Angeles, Calif.)
Mt. Lewis and Crescent Valley quadrangles (J. Gilluly, D)
Nevada Test Site, geologic studies (F. A. McKeown, D)
Nevada Test Site, Pahute Mesa (F. N. Houser, D)
Nevada Test Site, site studies (R. E. Davis, D)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Nevada—Continued
Nevada Test Site, underground air storage (R. B. Johnson, D)
Owyhee and Mountain City quadrangles (R. R. Coats, M)
Pioche district (C. M. Tschanz, La Paz, Bolivia)
Railroad district (J. F. Smith, Jr., D)
Schell Creek Range (H. D. Drewes, D)
Snake Range, Wheeler Peak and Garrison quadrangles (D. H. Whitebread, M)
Sonoma Range, northern, orogenic processes (J. Gilluly, D)
New Jersey:
Delaware River basin, lower (J. P. Owens, W)
Delaware River basin, middle (A. A. Drake, Jr., W)
Selected iron deposits (A. F. Buddington, Princeton, N.J.)
New Mexico:
Animas River area (H. Barnes, D)
Carrizo Mountains area (J. D. Strobell, D)
Franklin Mountains (R. L. Harbour, D)
Gila River basin, upper part (R. B. Morrison, D)
Grants area (R. E. Thaden, Columbia, Ky.)
Johnson Trading Post quadrangle (J. S. Hinds, c, Farmington)
Laguna district (R. H. Moench, D)
Las Vegas quadrangle, western half (E. H. Baltz, g, Albuquerque)
Manzano Mountains (D. A. Myers, D)
Mesa Portales quadrangle (J. E. Fassett, c, Farmington)
Nash Draw quadrangle (L. M. Gard, D)
Oscura Mountains, southern part, and northern San Andres Mountains (G. O. Bachman, D)
Raton coal basin, eastern (G. H. Dixon, D)
Raton coal basin, western (C. L. Pillmore, D)
San Juan Basin, east side (C. H. Dane, W)
Silver City area (W. R. Jones, D)
Valles Mountains, petrology (R. L. Smith, W)
New York:
Dannemora and Plattsburgh quadrangles—surficial geology (C. S. Denny, W)
Gouverneur area, metamorphism and origin of mineral deposits (A. E. J. Engel, La Jolla, Calif.)
Mooers and Ohio quadrangles (D. R. Wiesnet, W)
Richville quadrangle (H. M. Bannerman, W)
Selected iron deposits (A. F. Buddington, Princeton, N.J.)
Taconic sequence (E. Zen, W)
North Carolina:
Central Piedmont (H. Bell, W)
Franklin quadrangle (F. G. Lesure, W)
Grandfather Mountain (B. H. Bryant, D)
Great Smoky Mountains (J. B. Hadley, W)
Morganton area, geomorphic studies (J. T. Hack, W)
Mount Rogers area (D. W. Rankin, W)
Volcanic Slate series (A. A. Stromquist, D)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
North Dakota:
Dengate and Heart Butte NW quadrangles (E. V. Stephens, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
New Salem 2 SW and North Altmont quadrangles (H. L. Smith, c, D)
Oklahoma, Ft. Smith district (T. A. Hendricks, D)
Oregon:
Bandon SE and Coquille SW quadrangles (E. M. Baldwin, c, Los Angeles, Calif.)
Columbia River Gorge, Quaternary history (C. B. Hunt, Baltimore, Md.)
John Day area (T. P. Thayer, W)
Monument quadrangle (R. E. Wilcox, D)
Newport Embayment (P. D. Snavely, Jr., M)
Ochoco Reservation, Lookout Mountain, Eagle Rock, and Post quadrangles (A. C. Waters, Baltimore, Md.)
Pacific Islands:
Bikini and nearby atolls (H. S. Ladd, W)
Guam (J. I. Tracey, Jr., W)
Ishigaki, Ryukyu Islands (H. L. Foster, W)
Okinawa (G. Corwin, W)
Pagan Island (G. Corwin, W)
Palau Islands (G. Corwin, W)
Yap and Caroline Islands (C. G. Johnson, Honolulu, Hawaii)
Pennsylvania:
Allentown northeast quadrangle (J. M. Aaron, W)
Anthracite mine-drainage projects, geology in the vicinity of (J. F. Robertson, Mt. Carmel)
Anthracite region, flood control (M. J. Bergin, Mt. Carmel)
Bituminous coal resources (E. D. Pattersen, W)
Delaware River basin, lower (J. P. Owens, W)
Delaware River basin, middle (A. A. Drake, Jr., W)
Devonian stratigraphy of State (G. W. Colton, W)
Philadelphia district, Lower Cambrian (J. H. Wallace, W)
Southern anthracite field (G. H. Wood, Jr., W)
Washington County (H. Berryhill, Jr., D)
Western Middle anthracite field (H. Arndt, W)
Wind Gap and adjacent quadrangles (J. B. Epstein, W)
Puerto Rico (W. H. Monroe, San Juan, P.R.)
Rhode Island:
Ashaway and Voluntown quadrangles (T. G. Feininger, Boston, Mass.)
Ashaway and Watch Hills quadrangles—surficial (J. P. Schafer, Boston, Mass.)
Carolina and Quonochontaug quadrangles—surficial (J. P. Schafer, Boston, Mass.)
Chepachet, Crompton, and Tiverton quadrangles—bedrock (A. W. Quinn, Providence)
Clayville, Coventry Center, Kingston, Newport, and Prudence Island quadrangles—bedrock (G. E. Moore, Jr., Columbus, Ohio)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Rhode Island—Continued
Thompson quadrangle (P. M. Hanshaw, and H. R. Dixon, Boston, Mass.)
Watch Hill quadrangle (G. E. Moore, Jr., Columbus, Ohio)
Wickford quadrangle—bedrock (R. B. Williams, Lawrence, Kans.)
South Dakota:
Four Corners quadrangle (J. A. Van Lieu, Laramie, Wyo.)
Black Hills, southern (G. B. Gott, D)
Fort Randall Reservoir area (H. D. Varnes, D)
Harding County and adjacent areas (G. N. Pipiringos, D)
Hill City pegmatite area (J. C. Ratté, D)
Keystone pegmatite area (J. J. Norton, W)
Rapid City area (E. Dobrovolny, D)
Tennessee:
Ducktown district and adjacent areas (R. M. Hernon, D)
East Tennessee zinc studies (A. L. Brokaw, D)
Great Smoky Mountains (J. B. Hadley, W)
Ivydell and Pioneer quadrangles, Tennessee, and Jellico West and Ketchen quadrangles, Tennessee and Kentucky (K. J. Englund, W)
Knoxville and vicinity (J. M. Cattermole, Columbia, Ky.)
Mount Rogers area (D. W. Rankin, W)
Southern Appalachian folded belt, Kentucky, Tennessee, and Virginia (L. D. Harris, W)
Texas:
Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
Del Rio area (V. L. Freeman, D)
Franklin Mountains (R. L. Harbour, D)
North-central, Pennsylvanian Fusulinidae (D. A. Myers, D)
San Antonio and vicinity (R. D. Miller, D)
Sierra Blanca area (J. F. Smith, Jr., D)
Sierra Diablo region (P. B. King, M)
Utah:
Abajo Mountains (I. J. Witkind, D)
Alta quadrangle (M. D. Crittenden, Jr., M)
Bingham Canyon district (R. J. Roberts, M)
Circle Cliffs area (E. S. Davidson, Tucson, Ariz.)
Coal-mine bumps (F. W. Osterwald, D)
Confusion Range (R. K. Hose, M)
Crawford Mountains (W. C. Gere, c, Salt Lake City)
Elk Ridge area (R. Q. Lewis, Columbia, Ky.)
Green River valley, upper part (W. R. Hansen, D)
Gunsight Butte quadrangle (F. Peterson, c, D)
Hurricane fault, southwestern Utah (P. Averitt, D)
Kaiparowits Peak 4 quadrangle (H. D. Zeller, c, D)
Kolob Terrace coal field, southern part (W. B. Cashion, D)
La Sal area (W. D. Carter, W)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Utah—Continued
Lehi quadrangle (M. D. Crittenden, Jr., M)
Lisbon Valley area (G. W. Weir, Berea, Ky.)
Little Cottonwood area (G. M. Richmond, D)
Moab-Interriver area (E. N. Hinrichs, D)
Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
Nipple Butte quadrangle (H. A. Waldrop, c, D)
Oak City area (D. J. Varnes, D)
Ogden 1 SE and 4 quadrangles (T. A. Mullens, c, D)
Orange Cliffs area (F. A. McKeown, D)
Park City area (M. D. Crittenden, Jr., M)
Park City district (C. S. Bromfield, D)
Promontory Point (R. B. Morrison, D)
Sage Plain area (L. C. Huff, Manila, P.I.)
Salt Lake City and vicinity (R. Van Horn, D)
San Francisco Mountains (D. M. Lemmon, M)
San Rafael Swell (C. C. Hawley, D)
Sheeprock Mountains, West Tintic district (H. T Morris, M)
Snake Range, Wheeler Peak and Garrison quadrangles (D. H. Whitebread, M)
Strawberry Valley and Wasatch Mountains (A. A. Baker, W)
Thomas and Dugway Ranges (M. H. Staatz, D)
Tintic lead-zine district, eastern (H. T. Morris, M)
Uinta Basin oil shale (W. B. Cashion, D)
White Canyon area (R. E. Thaden, Columbia, Ky.)
Vermont:
North-central (W. M. Cady, D)
Rowe and Heath quadrangles (A. H. Chidester, D; J. H. Hartshorn, Boston, Mass.)
Virginia:
Big Stone Gap district (R. L. Miller, W)
Herndon quadrangle (R. E. Eggleton, M)
Mount Rogers area (D. W. Rankin, W)
Potomac Basin studies (J. T. Hack, W)
Southern Appalachian folded belt (L. D. Harris, W)
Washington, D.C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Washington:
Bald Knob quadrangle (M. H. Staatz, D)
Bodie Mountain quadrangle (R. C. Pearson, D)
Chewelah 1 quadrangle (L. D. Clark, M)
Columbia River Gorge, Quaternary history (C. B. Hunt, Baltimore, Md.)
Glacier Peak quadrangle (D. F. Crowder, M)
Grays Harbor basin, western part (H. C. Wagner, M)
Grays River quadrangle (E. W. Wolfe, M)
Holden and Lucerne quadrangles (F. W. Cater, D)
Hunters quadrangle (A. B. Campbell, D)
Inchelium quadrangle (A. B. Campbell, D)
Loomis quadrangle (C. D. Rinehart, M)
Maple Valley, Hobart and Cumberland quadrangles (J. D. Vine, M)

Geologic mapping—Continued
Map scale 1 inch to 1 mile, and larger—Continued
Washington—Continued
Metaline lead-zinc district (M. G. Dings, D)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
Olympic Peninsula, eastern (W. M. Cady, D)
Olympic Peninsula, northern (R. D. Brown, Jr., M)
Puget Sound Basin (D. R. Crandell, D)
Republic-Curlew area (R. L. Parker, D)
Seattle and vicinity (D. R. Mullineaux, D)
Stevens County (R. G. Yates, M)
Wilmont Creek quadrangle (G. E. Becraft, D)
West Virginia, Potomac Basin studies (J. T. Hack, W)
Wisconsin:
Florence County (C. E. Dutton, Madison)
Zinc-lead mining district (J. W. Whitlow, W)
Wyoming:
Adam Weiss Peak quadrangle (W. L. Rohrer, c, D)
Atlantic City district (R. W. Bayley, M)
Baggs area (G. E. Prichard, D)
Beaver Divide area (F. B. Van Houten, Princeton, N.J.)
Black Hills, Inyan Kara Group (W. J. Mapel, D)
Bradley Peak quadrangle (R. W. Bayley, M)
Carbon and Northern Laramie basins (H. J. Hyden, c, D)
Clark, Deep Lake, and Beartooth Butte quadrangles (W. G. Pierce, M)
Cokeville quadrangle (W. W. Rubey, Los Angeles, Calif.)
Crawford Mountains (W. C. Gere, Salt Lake City, Utah)
Crooks Gap area (J. G. Stephens, D)
Crowheart Butte area (J. F. Murphy, D)
Ferris quadrangle (R. L. Rioux, c, D)
Fish Lake and Kissinger Lakes quadrangles (W. L. Rohrer, c, D)
Fossil basin (J. I. Tracey, Jr., W)
Four Corners quadrangle (J. A. Van Lieu, Laramie, Wyo.)
Gas Hills district (H. D. Zeller, D)
Grand Teton National Park (J. D. Love, Laramie)
Jackson 30-minute quadrangle (D. A. Jobin, c. D)
LaBarge 1 SW and SE quadrangles (R. L. Rioux, c, D)
Lamont-Baroil area (M. W. Reynolds, D)
Oregon Buttes area (H. D. Zeller, c, D)
Powder River Basin, Pumpkin Buttes area (W. N. Sharp, D)
Sheep Mountain quadrangle (W. L. Rohrer, c, D)
Shirley Basin area (E. N. Harshman, D)
Spence-Kane area (R. L. Rioux, c, D)
Sweetwater County, Green River Formation (W. C. Culbertson, D)
Tepee Creek quadrangle (I. J. Witkind, D)
Wedding of Waters–Devil Slide quadrangles (E. K. Maughan, D)
Whalen-Wheatland area (L. W. McGrew, Laramie)

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Geophysics, regional—Continued
- Arkansas, Wichita Mountains system, aeromagnetic interpretation (A. Griscom, W)
- California:
  - Los Angeles basin, gravity study (T. H. McCulloh, Riverside)
  - Sacramento Valley and Coast Range, geophysical studies (G. D. Bath, M)
  - San Francisco Bay area, geophysical studies (G. D. Bath, M)
  - Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Colorado:
  - Arkansas Valley geophysical study (J. E. Case, D)
  - Cheyenne Mountain, electrical properties (J. H. Scott, D)
- District of Columbia, and vicinity, correlation of aeroradioactivity with geology (S. K. Neuschel, W)
- Iowa, central, aeromagnetic survey (J. R. Henderson, W)
- Maine:
  - Island Falls quadrangle, electromagnetic mapping (F. C. Frischknecht, W)
  - Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
- Maryland:
  - Montgomery County, geophysical studies (A. Griscom, W)
  - Washington, D.C., and vicinity, correlation of aeroradioactivity with geology (S. K. Neuschel, W)
- Massachusetts:
  - Application of geology and seismology to public-works planning (C. R. Tuttle and R. N. Oldale, Boston)
  - Geophysical studies (R. W. Bromery, W)
- Michigan:
  - Gogebic district, aeromagnetic study (J. E. Case, D)
  - Marquette district, aeromagnetic study (J. E. Case, D)
- Mississippi, Tatum salt dome (W. S. Twenhofel, D)
- Missouri, southeast, aeromagnetic study (J. W. Allingham, W)
- Montana:
  - Bearpaw Mountains, aeromagnetic study (K. G. Books, W)
  - Boulder batholith, aeromagnetic and gravity studies (W. E. Davis, M)
- Nevada:
  - Central Nevada, geophysical studies (D. R. Mabey, M)
  - Clark County, gravity investigations (M. F. Kane, W)
  - Nevada Test Site, aeromagnetic surveys (J. W. Allingham, W)
  - Nevada Test Site, soil conductivity measurements (J. H. Scott, D)
- New Jersey:
  - Gettysburg-Newark Basin, geophysical investigations (M. E. Beck, W)
  - New York-New Jersey Highlands, aeromagnetic studies (A. Jespersen, W)
- New Mexico, Valles caldera, geophysical study (H. R. Joesting, W)
- New York:
  - Adirondacks area, aeromagnetic studies (J. R. Balsley, W)
  - New York-New Jersey Highlands, aeromagnetic studies (A. Jespersen, W)
- North Carolina, Concord quadrangle, geophysical studies (R. G. Bates, W)
- Ohio, seismic survey for buried valleys (J. S. Watkins, W)
- Oregon:
  - Oregon Cascades, geophysical study (H. R. Blank, M)
  - West-central, aeromagnetic and gravity studies (R. W. Bromery, W)
- Pennsylvania:
  - Gettysburg-Newark Basin, geophysical investigations (M. E. Beck, W)
  - Gravity survey (R. W. Bromery, W)
  - Triassic area, aeromagnetic study (R. W. Bromery, W)
- Puerto Rico, geophysical studies (A. Griscom, W)
- South Dakota, Hills area, regional gravity studies (R. M. Hazlewood, D)
- Tennessee, central eastern, geophysical studies (J. S. Watkins, W)
- Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
- Utah:
  - Iron Springs areomagnetic survey (H. R. Blank, M)
  - Sheeprock Mountains, West Tintic district (D. R. Mabey, M)
- Virginia, Washington, D.C., and vicinity, correlation of aeroradioactivity with geology (S. K. Neuschel, W)
- Washington:
  - Northeastern, geophysical studies (W. T. Kinoshita, M)
  - Western, gravity survey (D. J. Stuart, D)
- West Virginia, Washington, D.C., and vicinity, correlation of aeroradioactivity with geology (S. K. Neuschel, W)
- Wisconsin:
  - Florence County, aeromagnetic study (E. R. King, W)
  - Wausau area, aeromagnetic studies (J. W. Allingham, W)
- Wyoming, Black Hills area, regional gravity studies (R. M. Hazlewood, D)

Geophysics, theoretical and experimental:
- Borehole geophysics as applied to geohydrology (W. S. Keys, h, D)
- Elastic and inelastic properties of earth materials (L. Peselnick, W)
- Electric and magnetic properties of minerals (A. N. Thorpe, W)
- Electrical effects of nuclear explosions (G. V. Keller, D)
- Electrical methods, development (C. J. Zablocki, D)
- Electrical properties of rocks (G. V. Keller, D)
- Electromagnetic exploration methods (F. C. Frischknecht, D)
- Electromagnetic radiation studies (W. A. Fischer, W)
- Geophysical abstracts (J. W. Clarke, W)
- Geophysical data, interpretation using electronic computers (R. G. Henderson, W)

Geophysics, theoretical and experimental—Continued
- Geothermal studies (A. H. Lachenbruch, M)
- Gravity and magnetic anomalies, analysis (W. H. Diment, W)
- Heat flow in the Appalachian Mountains (W. H. Diment, W)
- Heat transfer in salt (E. C. Robertson, W)
- Infrared and ultraviolet radiation studies (R. M. Moxham, W)
- Magnetic and luminescent properties (F. E. Senftle, W)
- Magnetic model studies (I. Zietz, W)
- Magnetic properties of crystals (A. N. Thorpe, W)
- Magnetic properties of rocks (A. Griscom, W)
- Nevada Test Site, soil conductivity measurements (J. H. Scott, D)
- Propagation of seismic waves in porous media (J. A. da-Costa h, Phoenix, Ariz.)
- Radon, geologic behavior (A. B Tanner, W)
- Remanent magnetization of rocks (R. R. Doell, M)
- Remote sensing of hydrologic phenomena (C. J. Robinove, w, St. Louis, Mo.)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Tension fractures and thermal investigation (A. H. Lachenbruch, M)
- Thermodynamic properties of rocks (R. A. Robie, W)
- Tiltmeter investigations (G. W. Greene, M)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)

Glacial geology:
- Alaska, glacial map (H. W. Coulter, W)
- Antarctica, Pensacola Mountains (A. B. Ford, W)
- California, west-central Sierra Nevada (F. M. Fryxell, Rock Island, Ill.)
- Greenland, Schuchert Dal (J. S. Hartshorn, Boston, Mass.)
- Washington–Oregon, Columbia River Gorge, Quaternary history (C. B. Hunt, Baltimore, Md.)

Glaciology:
- Glaciological research (M. F. Meier, h, Tacoma, Wash.)
- Alaska, Barrier Glacier (Mount Spurr) (G. C. Giles, c, Tacoma, Wash.)
- Montana:
  - Grinnell Glacier, hydrology (F. Stermitz, s, Helena)
  - Grinnell and Sperry Glaciers (Glacier National Park) (A. Johnson, c, W)
- Washington, Nisqually Glacier (Mount Rainier National Park) (G. C. Giles, c, Tacoma)

Gold:
- Gold deposits, United States (M. H. Bergendahl, D)
- Alaska:
  - Nome C–1 and D–1 quadrangles (C. L. Hummel, Bangkok, Thailand)
  - Tofty placer district (D. M. Hopkins, M)
- Colorado, Tenmile Range and Kokomo mining district (M. H. Bergendahl, D)
- Wyoming, Atlantic City district (R. W. Bayley, M)

Ground water–surface water relations:
- Bank-seepage studies (E. C. Pogge, s, Iowa City, Iowa)
- Flow losses in ephemeral stream channels (R. F. Hadley, h, D)

Ground water–surface water relations—Continued
- Ground water–surface water interrelations (M. W. Busby, s, Topeka, Kans.)
- Streamflow in relation to aquifer characteristics (G. R. Kunkle, s, W)
- California, water-loss and water-gain studies (E. G. Pearson, s, M)
- Florida, Lake Okeechobee, levee underseepage (F. W. Meyer, g, Tallahassee)
- Montana, Hungry Horse Reservoir, bank storage (A. F. Bateman, Jr., c, Great Falls)
- New Jersey, Ramapo River basin (J. Vecchioli, g, Trenton)
- New Mexico, White Sands Missile Range, research on paving a small watershed (H. O. Reeder, g, Albuquerque)
- Tennessee, Upper Buffalo River (W. J. Perry, w, Chattanooga)
- Washington:
  - Cedar River loss study, surface and ground water (F. T. Hidaka, s, Tacoma)
  - Columbia River basin, relation of ground-water storage and streamflow (M. I. Rorabaugh, h, Tacoma)
- Wisconsin, Little Plover River basin, hydrology (E. P. Weeks, g, D. W. Ericson, s, Madison)

Health, relation to distribution of elements:
- Distribution of radioactivity (S. Rosenblum, W)

Hydraulics, ground-water:
- Aquifer-test reevaluation, California (E. J. McClelland, g, Sacramento)
- Directional permeability and nonhomogeneity, mathematical relations (J. A. daCosta, h, Phoenix, Ariz.)
- Effects of heterogeneity (H. E. Skibitzke, h, Phoenix, Ariz.)
- Geohydrologic environmental studies (J. Norman Payne, h, Baton Rouge, La.)
- Mechanics of aquifers—principles of compaction and deformation (J. F. Poland, g, Sacramento, Calif.)
- Mechanics of fluid flow in porous media (A. Ogata, h, Honolulu, Hawaii)
- Permeability distribution study—Atlantic Coastal Plain (P. M. Brown, h, Raleigh, N.C.)
- Permeability research, California (A. I. Johnson, g, D)
- Regional hydrologic system analysis—hydrodynamics (R. R. Bennett, h, W)
- Regional hydrologic system analysis—permeability distribution (J. D. Bredehoeft, h, W)
- Research on laboratory and field methods (A. I. Johnson, g, D)
- Theory of multiphase flow—applications (R. W. Stallman, h, D)
- Theory of unsaturated flow (H. E. Skibitzke, h, Phoenix, Ariz.)
- Transient flow in saturated porous media (W. O. Smith, h, W)
- Treatise on ground-water mechanics (J. G. Ferris, g, Tucson, Ariz.)
- Unsaturated flow in porous media (W. O. Smith, h, W)
- Unsaturated-flow theory related to drainage and infiltration (Jacob Rubin, h, M)
- Unsteady flow to multiaquifer wells (I. S. Papadopulos, g, W)

- Paleontology, invertebrate, systematic—Continued
  - Corals, rugose:
    - Mississippian (W. J. Sando, W)
    - Silurian-Devonian (W. A. Oliver, Jr., W)
  - Foraminifera:
    - Cenozoic (R. Todd, W)
    - Cenozoic, California and Alaska (P. J. Smith, M)
    - Cretaceous (J. F. Mello, W)
    - Fusuline and orbitoline (R. C. Douglass, W)
    - Mississippian (B. A. L. Skipp, D)
    - Pennsylvanian-Permian, fusuline (L. G. Henbest, W)
    - Tertiary, larger (K. N. Sachs, Jr., W)
  - Gastropods:
    - Mesozoic (N. F. Sohl, W)
    - Miocene-Pliocene, Atlantic Coast (T. G. Gibson, W)
    - Oligocene, Mississippi (F. S. MacNeil, M)
    - Paleozoic (E. L. Yochelson, W)
  - Graptolites, Ordovician-Silurian (R. J. Ross, Jr., D)
  - Mollusks:
    - Cenozoic (F. S. MacNeil, M)
    - Late Cenozoic, nonmarine (D. W. Taylor, W)
  - Ostracodes:
    - Cenozoic (J. E. Hazel, W)
    - Lower Paleozoic (J. M. Berdan, W)
    - Upper Paleozoic (I. G. Sohn, W)
  - Pelecypods:
    - Inoceramid (D. L. Jones, M)
    - Jurassic (R. W. Imlay, W)
    - Oligocene, Mississippi (F. S. MacNeil, M)
    - Paleozoic (J. Pojeta, Jr., W)
    - Triassic (N. J. Silberling, W)
  - Radiolaria (K. N. Sachs, Jr., W)
  - Trilobites:
    - Cambrian (A. R. Palmer, W)
    - Ordovician (R. J. Ross, Jr., D)
- Paleontology, stratigraphic:
  - Cenozoic:
    - Coastal Plains (D. Wilson, W)
    - Diatoms:
      - California and Nevada (K. E. Lohman, W)
      - Nonmarine, Great Plains (G. W. Andrews, W)
    - Foraminifera:
      - Lodo Formation, California (M. C. Israelsky, M)
      - New Jersey coastal plain (H. E Gill, g, Trenton)
      - Smaller, Pacific Ocean and islands (M. R. Todd, W)
      - Trent Marl and related units (P. M. Brown, g, Raleigh, N.C.)
    - Miocene, Pacific Coast (W. O. Addicott, M)
    - Mollusks:
      - Alaska (F. S. MacNeil, M)
      - Oregon (E. J. Moore, M)
      - Western Pacific islands (H. S. Ladd, W)
    - Pollen and spores, Kentucky (R. H. Tschudy, D)
    - Vertebrates:
      - Atlantic coast (F. C. Whitmore, Jr., W)
      - Pacific coast (C. E. Repenning, M)
      - Panama Canal Zone(F. C. Whitmore, Jr., W)
      - Pleistocene (G. E. Lewis, D)
- Paleontology, stratigraphic—Continued
  - Mesozoic:
    - Cretaceous:
      - Foraminifera, Nelchina area, Alaska (H. R. Bergquist, W)
      - Gulf coast and Caribbean (N. F. Sohl, W)
      - Western interior United States (W. A. Cobban, D)
    - Jurassic, North American (R. W. Imlay, W)
    - Pacific coast (D. L. Jones, M)
    - Pierre Shale, Front Range area (W. A. Cobban and G. R. Scott, D)
    - Triassic marine faunas and stratigraphy (N. J. Silberling, M)
  - Paleozoic:
    - Cambrian (A. R. Palmer, W)
    - Corals, Redwall Limestone, Arizona (W. J. Sando, W)
    - Fusuline Foraminifera, Nevada (R. C. Douglass, W)
    - Mississippian:
      - Corals, northern Alaska (H. M. Duncan, W)
      - Stratigraphy and brachiopods, northern Rocky Mountains and Alaska (J. T. Dutro, Jr., W)
      - Stratigraphy and corals, northern Rocky Mountains (W. J. Sando, W)
    - Ordovician:
      - Stratigraphy and brachiopods, Eastern United States (R. B. Neuman, W)
      - Western United States (R. J. Ross, Jr., D)
    - Paleobotany and coal studies, Antarctica (J. M. Schopf, Columbus, Ohio)
    - Pennsylvanian:
      - Fusulinidae, north-central Texas (D. A. Myers, D)
      - Spores and pollen, Kentucky (R. M. Kosanke, D)
    - Permian:
      - Floras, Southwest United States (S. H. Mamay, W)
      - Stratigraphy and brachiopods, Southwest United States (R. E. Grant, W)
    - Silurian-Devonian:
      - Corals, Northeastern United States (W. A. Oliver, Jr., W)
      - Great Basin and Pacific coast (C. W. Merriam, M)
      - Upper Silurian-Lower Devonian, Eastern United States (J. M. Berdan, W)
      - Subsurface rocks, Florida (J. M. Berdan, W)
    - Type Morrow Series, Washington County, Ark. (L. G. Henbest, W)
    - Upper Paleozoic, Great Basin (M. Gordon, Jr., W)
- Paleontology, vertebrate, systematic:
  - Artidactyls, primitive (F. C. Whitmore, Jr., W)
  - Pleistocene fauna, Big Bone Lick, Ky. (F. C. Whitmore, Jr., W)
  - Tritylodonts, American (G. E. Lewis, D)
- Paleotectonic maps. *See* Regional studies and compilations.
- Pegmatites:
  - North Carolina:
    - Franklin quadrangle (F. G. Lesure, W)
    - Southern Blue Ridge Mountains, mica deposits (F. G. Lesure, W)

Sedimentation—Continued
- Missouri, St. Louis, special sediment investigations at Mississippi River (C. H. Scott, q, Lincoln, Nebr.)
- Nebraska, Little Blue River basin, fluvial sediment and quality of water (J. C. Mundorff, q, Lincoln, Nebr.)
  - Medicine Creek basin, erosion and deposition (J. C. Brice, q, Lincoln)
- New Jersey, Stony Brook watershed, fluvial sedimentation (J. R. George, q, Philadelphia, Pa.)
- North Carolina, upper Yadkin River basin, sediment yield (H. E. Reeder, q, Raleigh)
- Oregon, Alsea River basin, sedimentation in forested drainage areas (R. C. Williams, q, Portland)
- Pennsylvania, Bixler Run watershed, hydrology and sedimentation (J. R. George, q, Philadelphia)
  - Conestoga Creek watershed, sedimentation (J. R. George, q, Philadelphia)
  - Corey Creek and Elk Run watershed (J. R. George, q, Philadelphia)
  - Sedimentation Statewide (J. R. George, q. Harrisburg)
  - Susquehanna River basin, fluvial sediment reconnaissance (J. R. George, q, Harrisburg, Pa.)
- Texas, reconnaissance sediment investigations (C. T. Welborn, q, Austin)
  - Upper Trinity River basin, sedimentation (C. H. Hembree, q, Austin)
- Washington, Chehalis River basin, sedimentation and chemical quality of surface waters (P. A. Glancy, q, Portland, Oreg.)
  - Palouse River basin, sedimentation and chemical quality of surface waters (P. R. Boucher, q, Portland, Oreg.)
  - Walla Walla River basin, sedimentation and chemical quality of surface waters (B. E. Mapes, q, Portland, Oreg.)
- Wisconsin, reconnaissance sediment investigations (C. R. Collier, q, Columbus, Ohio)
- Wyoming, Wind River basin, sedimentation and chemical quality of surface waters (D. C. Dial, q, Worland)
- *See also* Geomorphology *and* Quality of water.

Sedimentation, reservoirs:
- California, Stony Gorge Reservoir (J. M. Knott, q, Sacramento)
- Colorado, Kiowa Creek basin, K–79 reservoir (R. Brennan, q, D)
- Georgia, North Fork Broad River, subwatershed 14 near Avalon (D. E. Shattles, q, Ocala, Fla.)
- Louisiana, Bayou Dupont watershed, reservoir (S. F. Kapustka, q, Baton Rouge)
- Nevada, Peavine Creek (J. E. Parkes, w, Carson City)
- New Jersey, Baldwin Creek reservoir (J. R. George, q, Philadelphia, Pa.)
- Texas, Escondido Creek (C. H. Hembree, q, Austin)
- Utah, Paria River basin, Sheep Creek near Tropic sediment barrier (G. C. Lusby, w, D)

Selenium. *See* Minor elements.

Silica:
- Oriskany Formation (W. D. Carter, W)
- Tintic Quartzite (K. B. Ketner, D)

Soil moisture:
- Effect of mechanical treatment on arid lands in the Western United States (F. A. Branson, w, D)
- Effects of grazing exclusion, Badger Wash area, Colorado (G. C. Lusby, w, D)
- Iron distribution, water movement in soils, and vegetation (R. F. Miller, w, D)
- Plant and soil-water response to thermal gradient, Ogallala Formation (F. A. Branson, w, D)
- Plants as indicators of soil-moisture availability (F. A. Branson, w, D)

Spectroscopy:
- Mobile spectographic laboratory (F. N. Ward, D)
- Spectrographic analytical services and research (A. W. Helz, W; A. T. Myers, D; H. Bastrom, M)
- X-ray spectroscopy (H. J. Rose, Jr., W; W. W. Brannock, M)

Springs:
- Discharge of Rattlesnake Springs and nearby irrigation wells, Eddy County, N. Mex. (E. R. Cox, g., Albuquerque)
- Springs of California (C. F. Berkstresser, Jr., q, Sacramento)
- Springs of Colorado (J. A. McConaghy, g, D)

Stratigraphy and sedimentation:
- Atlantic Coastal Plain:
  - Regional synthesis (J. C. Maher, M)
  - Southern part (J. E. Johnston, W)
- Basement rock map of United States (R. W. Bayley, M)
- Cave deposits, stratigraphy and mineralogy (W. E. Davies, W)
- Colorado Plateau:
  - Lithologic studies (R. A. Cadigan, D)
  - San Rafael Group, stratigraphy (J. C. Wright, W)
  - Stratigraphic studies (L. C. Craig, D)
  - Triassic stratigraphy and lithology (J. H. Stewart, M)
- East coast continental shelf and margin (J. S. Schlee, Woods Hole, Mass.)
- Front Range, Pennsylvanian and Permian stratigraphy (E. K. Maughn, D)
- Green River Formation, tuffs (R. L. Griggs, D)
- Northern Rocky Mountains and Great Plains, Middle and Late Tertiary history (N. M. Denson, D)
- Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)
- Pierre Shale:
  - Paleontology and stratigraphy, Front Range area (W. A. Cobban, G. R. Scott, D)
  - Montana, North Dakota, South Dakota, Wyoming, and Nebraska, chemical and physical properties (H. A. Tourtelot, D)
- Sedimentary environments, classification (E. J. Crosby, D)
- Sedimentary mineralogy (P. D. Blackmon, D)
- Sedimentary-petrology laboratory (H. A. Tourtelot, D)
- Sedimentary structures, model studies (E. D. McKee, D)
- Subsurface-data center (L. C. Craig, D)
- Upper Jurassic stratigraphy, northeast Texas, southwest Arkansas, northwest Louisiana (K. A. Dickinson, D)

Water resources—Continued
- Colorado (Denver)—Continued
  - Ground water:
    - Occurrence and development in State (J. A. McConaghy, g)
    - Summary of pumping tests in State (W. W. Wilson, g)
    - Bent County (J. H. Irwin, g)
    - Big Sandy Valley below Limon (D. L. Coffin, g)
    - Colorado High Plains, trends in ground-water development (A. J. Boettcher, g)
    - Denver Basin (G. H. Chase, g)
    - Denver Basin, ground-water trends (C. A. J. Boettcher, g)
    - East-central, Quaternary deposits (H. E. McGovern, g)
    - Parts of Larimer, Logan, Morgan, Sedgwick, and Weld Counties (W. G. Weist, g)
    - Pueblo and Fremont Counties (H. E. McGovern, g)
    - Southeastern, bedrock aquifers (J. H. Irwin, g)
    - Ute Mountain-Ute Indian Reservation (J. H. Irwin, g)
- Connecticut (q, s, Hartford; g, Middletown):
  - Ground water, Hamden-Wallingford area (A. M. La Sala, Jr, g)
  - Water resources of Connecticut:
    - Part 1, Quinebaug River basin (A. D. Randall, g)
    - Part 2, Shetucket River basin (M. P. Thomas, s)
    - Part 3, Thames River basin (C. E. Thomas, Jr., q)
- Florida (g, Tallahassee; s, q, Ocala):
  - Statewide, special studies (C. S. Conover, g; K. A. MacKichan, q; A. O. Patterson, s)
  - Water atlas (W. E. Kenner, s)
  - Ground water:
    - Cape Canaveral area, Brevard County, geohydrology (D. W. Brown, g)
    - Dade County, special studies (H. Klein, g)
    - Dade County, Area B, special studies (F. A. Kohout, g)
    - Duval, Nassau, and Baker Counties (G. W. Leve, g)
    - Fort Lauderdale area, special studies (H. Klein, g)
    - Marion County (F. N Visher, g)
    - Polk County (H. G. Stewart, g)
    - Venice well field, Sarasota County, geohydrology (W. E. Clark, g)
  - Water resources:
    - Broward County (C. B. Sherwood, g)
    - Econfina Creek basin area (R. H. Musgrove, s)
    - Escambia and Santa Rosa Counties (R. H Musgrove, s)
    - Everglades National Park (J. H. Hartwell, s)
    - Green Swamp area (R. W. Pride, s)
    - Lower Hillsboro Canal area (R. G. Grantham, q)
    - Middle Gulf basins (R. N. Cherry, q)
    - Myakka River basin (B. F. Joyner, q)
    - Orange County (W. F. Lichtler, g)
- Georgia (Atlanta):
  - River-systems studies (A. N. Cameron, s)

Water resources—Continued
- Georgia (Atlanta)—Continued
  - Ground water:
    - Floyd and Polk Counties (C. W. Cressler, g)
    - Seminole, Decatur, and Grady (C. W. Sever, g)
  - Water resources:
    - Cook County (C. W. Sever, g)
    - Pulaski County (R. C. Vorhis, g)
    - Rockdale County (M. J. McCollum, g)
    - Thomas County, Cairo area (C. W. Sever, g)
    - Thomas, Brooks, and Colquitt Counties (C. W. Sever, g)
- Guam, (Honolulu, Hawaii):
  - Ground water (D. A. Davis, g)
  - Surface water (S. H. Hoffard, s)
- Hawaii (Honolulu):
  - Hydrologic studies (G. T. Hirashima, s)
  - Water production from the Waiaha catchment area, Hawaii (S. S. Chinn, s)
  - Water resources:
    - Hilo-Puna area, Hawaii, reconnaissance (G. Yamanaga, s)
    - Kahuku area, Oahu (K. J. Takasaki, g)
    - Kau area, Hawaii, reconnaissance (D. A. Davis, g)
    - Mokuleia-Waialua area, Oahu (J. C. Rosenau, g)
    - Waianae district, Oahu (C. P. Zones, g)
    - Windward Oahu (K. J. Takasaki, g)
- Idaho (Boise):
  - Little Lost River basin, water resources (H. A. Waite, g)
  - Ground water:
    - Aberdeen-Springfield area (H. G. Sisco, g)
    - American Falls (M. J. Mundorff, g)
    - Artesian City–Oakley area (E. G. Crosthwaite, g)
    - Lower Teton Basin (E. G. Crosthwaite, g)
    - Mud Lake Basin (P. R. Stevens, g)
    - Salmon Falls Creek area (E.G. Crosthwaite, g)
- Indiana (Indianapolis):
  - Ground water:
    - Delaware County (R. E. Hoggatt, g)
    - Northwestern (J. D. Hunn, g)
    - West-central (L. W. Cable, g)
- Iowa (Iowa City):
  - Availability and utilization of water in central Iowa (F. W. Twenter, R. W. Cole, g)
  - Ground water:
    - Cerro Gordo County (W. L. Steinhilber, g)
    - Linn County (R. E. Hansen, g)
    - The Mississippian aquifer of Iowa (P. J. Horick, W. L. Steinhilber, g)
    - Water availability from glacial deposits of south-central Iowa (J. W. Cagle, g)
- Kansas (Lawrence):
  - Ground water:
    - Brown County (C. K. Bayne, g)
    - Butler County (J. M. McNellis, g)
    - Cherokee County (W. J. Seevers, g)
    - Decatur County (W. G. Hodson, g)
    - Ellsworth County (C. K. Bayne, g)

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Water resources—Continued
- Missouri (Rolla):
  - Water resources of the Joplin area (E. J. Harvey, g)
- Montana (Billings):
  - Ground water:
    - Bitterroot Valley, Ravalli County (R. G. McMurtrey, g)
    - Cedar Creek anticline, west flank (O. J. Taylor, g)
    - Deer Lodge Valley (R. L. Konizeski, g)
    - Fort Belknap Indian Reservation (D. C. Alverson, g)
    - Frazier-Wolf Point irrigation project (W. B. Hopkins, g)
    - Judith Basin, western part (E. A. Zimmerman, g)
    - Lower Bighorn River valley Hardin Unit (L. J. Hamilton, g)
    - Missoula Valley (R. G. McMurtrey, g)
- Nebraska (Lincoln):
  - Geology and hydrology of Saline County (P. A. Emery, g)
  - Ground water:
    - Adams County, availability of ground water (C. F. Keech, g)
    - Fillmore County (C. F. Keech, g)
    - York County (C. F. Keech, g)
- Nevada (Carson City):
  - Hydrology of a portion of the Humboldt River valley (P. Cohen, W)
  - Ground water:
    - Coyote Spring, Kane Spring, and Muddy River Springs area (T. E. Eakin, w)
    - Dixie and Fairview Valleys (P. Cohen, D. E. Everett, w)
    - Eagle Valley (G. F. Worts, Jr., w)
    - Edwards Creek Valley (D. E. Everett, w)
    - Kings River valley (G. T. Malmberg, w)
    - Lake Valley (F. E. Rush, w)
    - Monitor, Antelope, and Kobeh Valleys (F. E. Rush, w)
    - Pahrump Valley (G. T. Malmberg, w)
    - Quinn River valley (C. J. Huxel, Jr., w)
    - Smith Creek valley (D. E. Everett, w)
    - Spring Valley (F. E. Rush, w)
    - Upper Reese River valley (F. E. Rush, w)
    - Washoe Valley (G. F. Worts, Jr., w)
    - White River valley system (T. E. Eakin, w)
- New Hampshire (Boston, Mass.):
  - Ground water, lower Merrimack River basin (J. M. Weigle, g)
- New Jersey (Trenton):
  - Drought in the Delaware River basin, (J. E. McCall, s)
  - Water budget of Great Swamp (E. G. Miller, s)
  - Ground water:
    - Camden County (E. Donsky, g)
    - Cumberland County (J. G. Rooney, g)
    - Essex County (J. Vecchioli, g)
    - Morris County (H. E. Gill, g)
    - Ocean County (H. R. Anderson, g)
    - Pine Barrens (E. C. Rhodehamel, g)
    - Rahway area (H. R. Anderson, g)

Water resources—Continued
- New Jersey (Trenton)—Continued
  - Ground water—Continued
    - Water-level fluctuations in New Jersey, 1958–62 (C. R. Austin, g)
    - Wharton Tract (E. C. Rhodehamel, g)
- New Mexico (Albuquerque):
  - Evaluation of pumping effects in the Malaga Bend area, Eddy County (E. R. Cox, g)
  - Evaluation of well-field data at Los Alamos (R. L. Cushman, g)
  - Hydrologic almanac of State (W. E. Hale, g)
  - Hydrology of damsites on the Mescalero Apache Indian Reservation (J. S. Havens, g)
  - Miscellaneous activities under the New Mexico State Engineer program (L. V. Davis, g)
  - Water supply for Los Alamos (R. L. Cushman, g)
  - Ground water:
    - Fort Bayard Hospital, Grant County, geology and ground-water resources (F. D. Trauger, g)
    - Gila Cliff Dwellings National Monument, Catron County (F. D. Trauger, g)
    - Grant County (F. D. Trauger, g)
    - Guadalupe County (A. Clebsch, Jr., g)
    - Lake McMillan and Carlsbad Springs, ground-water conditions between (E. R. Cox, g)
    - Luna County, southern (G. C. Doty, g)
    - MAR Facility water supply (G. C. Doty, g)
    - McKinley County, southeastern (J. B. Cooper, g)
    - McMillan delta area (E. R. Cox, g,)
    - Mesita, Laguna Indian Reservation, ground-water exploration (G. A. Dinwiddie, g)
    - Pojoaque Pueblo Grant, Santa Fe County, availability of ground water for irrigation (G. A. Dinwiddie, g)
    - Quay County (W. A. Mourant, g)
    - Roswell basin, Chaves and Eddy Counties, quantitive analysis of the ground-water system (G. E. Maddox, g)
    - San Juan County, northern (F. D. Trauger, g)
    - Sandia and Manzano Mountains area (F. B. Titus, g)
    - Torreon and Ojo Encino School wells (G. A. Dinwiddie, g)
    - White Sands Integrated Range, northern (J. E. Weir, g)
    - White Sands Missile Range, reconnaissance, ground-water resources at selected sites (G. C. Doty, g)
  - Zuni Reservation water supply (S.W. West, g)
- New York (Albany):
  - Ground water:
    - Jamestown area (L. J. Crain, g)
    - Nassau County (N. M. Perlmutter, g)
    - Nassau County, northeast (J. Isbister, g)
    - Orange and Ulster Counties (M. H. Frimpter, g)
    - Queens County (J. Soren, g)
    - Rensselaer County, Schodack terrace (J. Joyce, g)
    - Schenectady County, eastern (J. D. Winslow, g)
    - Suffolk County, mid-island area (J. Soren, g)
    - Syracuse area (I. H. Kantrowitz, g)

Water resources—Continued
South Dakota (Huron)—Continued
Ground water—Continued
Lake Madison–Skunk Creek drainage basin (M. J. Ellis, g)
Pine Ridge Indian Reservation (M. J. Ellis, g)
Sanborn County (L. W. Howells, g)
Studies of artesian wells and selected shallow aquifers (C. F. Dyer, g)
Tennessee (Chattanooga):
Ground water:
Germantown-Collierville area (D. J. Nyman, w)
Highland Rim Plateau (D. T. Marsh, W)
Memphis area (E. A. Bell, w)
Water resources:
Lawrence County (R. H. Bingham, w)
Lewis County (R. H. Bingham, w)
Montgomery County (G. K. Moore, w)
Trace Creek (J. H. Criner, Jr., w)
Texas (Austin):
Annotated bibliography of ground-water literature (R. C. Baker, g)
Permian Basin program—eastern problem area (P. R. Stevens, h)
Hydrologic investigations:
Deep Creek (W. B. Mills, s)
Escondido Creek (F. W. Kennon, s)
Little Elm Creek (E. E. Schroeder, s)
Mukewater Creek (S. P. Sauer, s)
Trinity, Brazos, Colorado, and San Antonio River basins (C. R. Gilbert, s)
Ground water:
Atascosa and Frio Counties (Roger C. Baker, g)
Bee County (B. N. Myers, g)
Brazos River alluvium, occurrence and availability of ground water (J. G. Cronin, g)
Caldwell County (C. R. Follett, g)
Camp, Franklin, Morris, and Titus Counties (M. E. Broom, g)
Carson and part of Gray County (G. McAdoo, g)
Conzales County (G. H. Shafer, g)
DeWitt County (C. R. Follett, g)
El Paso area, continuing quantitative studies (M. E. Davis, g)
Gaines County (P. L. Rettman, g)
Galveston County (R. K. Gabrysch, g)
Guadalupe County (G. H. Shafer, g)
Hardin County (E. T. Baker, Jr., g)
Harrison County (M. E. Broom, g)
Houston County, occurrence and availability of ground water (G. H. Tarver, g)
Houston district, continuing quantitative studies (R. K. Gabrysch, g)
Jackson County (E. T. Baker, Jr., g)
Jasper and Newton Counties (J. B. Wesselman, g)
LaSalle and McMullen Counties (H. B. Harris, g)
Lee County (G. L. Thompson, g)
Menard County (R. C. Baker, g)
Orange County (J. B. Wesselman, g)

Water resources—Continued
Texas (Austin)—Continued
Ground water—Continued
Padre Island National Seashore (B. N. Myers, g)
Refugio County (C. C. Mason, g)
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PROFESSIONAL PAPER 501–B

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PROFESSIONAL PAPER 501–D

PUBLICATIONS IN FISCAL YEAR 1964

A complete list of abstracts, papers, reports, and maps (exclusive of topographic maps) by U.S. Geological Survey authors published or otherwise released to the public during fiscal year 1964 (July 1, 1963–June 30, 1964) is given below. Publications are listed alphabetically by senior author. Each citation is identified by a number: for example, 1–64, which indicates the first entry for that author for the calendar year 1964. The number is followed by the names of coauthors and the citation itself. References to this list are identified in the preceding text by author and serial number; for example, Schmidt (1–63).

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