GEOLOGICAL SURVEY RESEARCH 1969

Chapter A
NHP PP 650-A
U.S. Geological Survey
Geological Survey Research
1969 - Chapter A
Significant results of investigations for fiscal year 1969, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as Chapters A, B, C, and D.
A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal year 1969, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping.
"Geological Survey Research 1969," the tenth annual review of the economic and scientific work of the U.S. Geological Survey, consists of four chapters (A through D) of Professional Paper 650. Chapter A summarizes significant results, and the remaining chapters consist of collections of short technical papers. As in the past the purpose of the volume is to make available promptly to the public many of the highlights of Survey research and investigations.

Some, but not all, of the results summarized in chapter A are discussed in more detail in the short technical papers of chapters B through D, or in reports listed in "Publications in Fiscal Year 1969", beginning on page A291. The tables of contents for chapters B through D are listed on pages A285-A290 of this chapter.

Numerous Federal, State, county, and local agencies and other organizations and countries listed on pages A239-A244 made significant financial contributions to the results reported here. They are identified where appropriate in the short technical papers (chapters B-D), and in papers published cooperatively, but are not generally identified in the summary statements of chapter A. However, if a summary statement is the result of collaboration with a colleague from outside the Survey, the colleague's current organization (such as a university) is indicated in parentheses immediately following his name in the text.

The volume for next year, "Geological Survey Research 1970," will be published as chapters of Professional Paper 700. Previous volumes are listed below, with their series designations.

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William T. Pecora,  
Director.
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REFERENCES

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R. A. Sheppard and A. J. Gude III (p. D69-D74)


J. B. Cathcart (r2058)

Refers to a publication released in fiscal year 1969 and at least one of whose authors is a member of the U.S. Geological Survey. The number is the acquisition number used in computer compilation of the list of publications that begins on p. A291. (In the text, the prefix "r" replaces the first cipher of the acquisition numbers in the list.)

Footnotes

Used for those publications that were released before or after fiscal year 1969, or that are in press, or whose authors are not members of the U.S. Geological Survey.

ABBREVIATIONS

[Singular and plural forms for abbreviations of units of measure are the same]

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RESOURCES INVESTIGATIONS

SPECIAL AND TOPICAL MINERAL-RESOURCE PROGRAMS

HEAVY METALS

ALASKA

Geochemical anomalies in the eastern Brooks Range

Reconnaissance stream sediment sampling by W. P. Brosge and H. N. Reiser in the Chandalar quadrangle and the eastern part of the Wiseman quadrangle on the south slope of the Brooks Range in eastern Alaska (locality 1, index map) revealed only two conspicuous regional anomalies; these coincide with the two known gold mining districts near Wiseman and Chandalar. A third anomalous area is suggested by the clustering of samples with anomalous amounts of silver in a zone along the contact between granite and carbonate rock north of the mining districts. The concentration of silver is not high, but silver is known to occur in galena at one prospect and as nuggets in a stream placer in the area.

Chulitna-Yentna mineral belt, central Alaska Range

A mineralized belt called the Chulitna-Yentna belt by C. C. Hawley and A. L. Clark is defined by lode occurrences, geochemical anomalies, and placer deposits derived from lodes within the belt. It extends for more than 100 miles along the southern flank of the central Alaska Range, at least from Collinsville on the south to Bull River in the north, and goes through the Yentna, Curry, and upper Chulitna districts (loc. 2). The belt is subparallel to the regional strike of rock units and faults, and in its northern part it is subparallel to elongate serpentinite masses which locally contain chromite.

Mineral deposits of the belt are characterized primarily by arsenic and gold and subordinately by silver, lead, zinc, antimony, bismuth, and tin. The main deposit of the northern part of the belt is the Golden Zone. Other principal deposits are newly identified occurrences at Costello Creek and Lookout Mountain and vein and associated disseminated deposits in basalt and limestone host rocks at Partin and Canyon Creeks. The main deposits of the southern part are placer gold deposits of the Cache Creek-Peters Creek basin in the Yentna district. These placers were derived from the erosion of small but rich lode deposits such as those at Bird Creek and probably from erosion of lower grade deposits in major shear zones. Arsenic and gold are ubiquitous elements of the belt; less abundant but diagnostic elements include copper, antimony, tin and bismuth.

ARIZONA

Gold placer and lode deposits, Gold Basin and Lost Basin

P. M. Blacet's studies of lode and placer gold deposits in the Gold Basin-Lost Basin area south of Lake Mead in northwestern Arizona (locality 1, index map) indicate that detrital gold, eroded from Upper Pre-cambrian (?) quartz-carbonate-sulfide-gold veins, is widely distributed in fanglomerate of late Tertiary and Quaternary age. Placer mining of unconsolidated arroyo gravels largely derived from underlying Pliocene (?) fanglomerates was done over an area of 8 to 10 sq mi in the vicinity of the King Tut mine. The gold content of these arroyo gravels is highly variable, but the average grade mined since their discovery in 1931 has probably been about 0.04-0.05 oz gold per cu yd. Little is known about the average content or distribution of gold in the parent fanglomerates, but it appears geologically reasonable that the potential gold resources in the King Tut area may exceed 500 million cu yd of gravel averaging 0.01-0.02 oz gold per cu yd. Accurate sampling of the fanglomerates is made diffi-
cult by the coarseness of the detrital gold (commonly more than 50 percent of the gold is in ragged grains a millimeter or more across) and by its seemingly erratic distribution.

Careful examination of coarse placer gold indicated that nuggets at least as large as 0.35 oz are of detrital rather than accretionary origin. Rhombohedral and cubic molds, as well as pyrite pseudomorphs, are commonly well preserved in the coarse placer gold, and measurement of interfacial angles has established that much of the coarse gold was originally deposited on euhedral clusters of ferruginous carbonate, possibly ankerite. The lode source of this coarse gold is uncertain, but pyrite and ankeritic carbonate are abundant in the veins of the area, although lode gold coarser than 2–3 mm in average dimension has not yet been observed.

Two types of lode gold deposits were recognized by Blacet in the Precambrian rocks of the Gold Basin-Lost Basin, area.

Gold-bearing quartz-carbonate-sulfide veins are widely distributed in both a complexly deformed amphibolite-facies metasedimentary sequence and in Upper Precambrian (?) granodiorite plutonic rocks. These veins commonly contain appreciable amounts of feldspar, and locally appear transitional into carbonate- and sulfide-bearing pegmatites.

The second type of lode deposit consists of small intrusive bodies of gold-bearing medium-grained, porphyritic leucosyenite containing several percent of interstitial fluorite. Miarolitic cavities in this leucosyenite contain small euhedral crystals of parisite \((Ca(CO_3)_2(F_2))\). Megascopically visible gold is disseminated throughout the leucosyenite and appears to be primary. The leucosyenite is tentatively considered to have crystallized in small pipelike conduits during late magmatic escape of highly potassic residual liquids that were enriched in \(H_2O\), \(HF\), \(CO_2\), \(SO_2\), \(Zr\), \(Au\), and rare earths. A Late Precambrian age is suspected for both the veins and the leucosyenite pipes, and these two types of deposits are thought to be cogenetic.

### CALIFORNIA

**Seismic studies of Tertiary gravels, Sierra Nevada**

Seismic refraction work within the hydraulic pit near North Columbia, Nevada County (locality 1, index map), enabled a prediction of bedrock depths to within 10 percent of the actual values as determined by drilling; thus, according to W. E. Yeend, this method seems feasible for determining bedrock depths beneath 300 to 450 feet of gold-bearing gravel. However, the use of seismic refraction and gravity methods for determining bedrock configuration beneath 600 to 1,000 feet of sands, clays, and volcanic breccia such as occur on San Juan Ridge seems infeasible at this time. Lateral changes of density and velocities within both the volcanic breccia and the sands and clays beneath the volcanic rocks limit the ability to accurately interpret seismic and gravity data.

### COLORADO

**Silver and copper in McElmo Canyon**

The Bluff Sandstone (Upper Jurassic) in a west-northwest-striking shear zone which passes through Battle Rock in McElmo Canyon, Montezuma County, (locality 1, index map) was reported by R. A. Cadigan to contain anomalously high amounts of silver (4 to 50 ppm) and copper (270 to 14,000 ppm) for at least a mile west-northwest of the Battle Rock prospect. The prospect and the Karla Kay uranium mine, 2 miles west-northwest, appear to lie on the same shear zone. A wide fault zone that strikes northeast intersects the Battle Rock shear zone about 1 mile west-northwest of Battle Rock. Anomalous copper and detectable gold were found in one locality in the Entrada Sandstone
(Upper Jurassic) in the fault zone 3 miles northeast of Battle Rock, and samples of mud from a carbon dioxide well 0.3 mile north of this locality showed high copper (70 ppm) and silver (1.6 ppm) and detectable gold (0.02 ppm). Bluff Sandstone in the fault zone at its intersection with the McElmo Canyon road contains high silver (2 ppm). Results of the geochemical study to date suggest that the fault and shear zones contain the highest metal anomalies and probably contain or lie adjacent to any economically important metal deposits that may be present in the area.

**Ore deposits of Chicago Basin**

In the Chicago Basin district of the Needle Mountains in southwestern Colorado (loc. 2), L. J. Schmitt identified two hypabyssal porphyries of possible Tertiary age that intrude Precambrian granite. The older alkaline quartz porphyry is pervasively altered and locally mineralized, whereas the younger rhyolite porphyry is less altered and appears to be barren. Intensely sericitized and silicified prophyry contains anomalous amounts of arsenic, gold, copper, molybdenum, antimony, and tin, particularly on the west side of the older porphyry. Anomalous amounts of silver, lead, and zinc are more widely distributed and are also somewhat concentrated on the western side.

The granite enclosing the porphyry complex is cut by numerous fractures and quartz veins. Most pyritic quartz veins containing shoots of base and precious metal ores are along a belt more than 4 miles long and about 2 miles wide that trends north-northwest. Veins are along regional sets of joints, along fractures radiating from intrusive centers, and along fractures that follow no regional trend. Geochemical anomalies of lead and zinc show a zonal distribution around the intrusive center, whereas molybdenum is distributed along the entire north-northwest-trending belt.

**Gold in Castle Rock Conglomerate**

In the Castle Rock area of Douglas County (loc. 3), gold in modern stream alluvium is derived from reworking of fossil placers in the Castle Rock Conglomerate, of early Oligocene age. Electron microprobe studies by G. A. Desborough indicate that individual gold grains originating from the Castle Rock Conglomerate average more than 96 percent gold; the remainder is chiefly silver. Most of the gold grains are less than 1 mm across, and some are as small as 0.10 mm. Paleocurrent studies indicate that the primary source of the gold apparently is not the Georgetown-Central City area to the northwest as previously thought, but rather is an area to the west or southwest of the town of Castle Rock, either in the Front Range or possibly as far west as the headwaters of the Platte River. At present it is not known whether the primary source of the gold has been completely removed by erosion or is concealed by sediments or faulting of post-Eogocene age.

**Niobium and other elements, Gem Park**

Concentrations of niobium and rare earth and other elements were found by R. L. Parker and W. N. Shrop in the carbonatite dikes and altered pyroxenite and gabbro of the Gem Park complex, a composite funnel-shaped intrusive 11 miles northwest of Westcliffe (loc. 4). The location and arrangement of fenite and carbonatite dikes in the complex suggest the existence of an unexposed massive carbonatite at an unknown depth near the center of the complex. Such a mass could be rich in niobium, thorium, rare-earth elements, and others.

**MONTANA**

**Geochemistry and geochronology, Virginia City**

About 900 reconnaissance soil samples collected by K. L. Wier in the Virginia City mining district, Madison County (locality 1, index map), were analyzed for gold and other metals. Known gold-bearing areas were detected, indicating that detailed soil sampling may reveal gold mineralization in places where residual soil covers bedrock.

**NEVADA**

**Geochemical investigations at Virginia City**

Reconnaissance geochemical sampling by D. H. Whitebread of altered volcanic rocks in the Comstock mining district, Virginia City, Storey County, (locality 1, index map), revealed anomalous amounts of mercury in the Cornwall Knob and Washington Hill areas, about 5 and 11 miles, respectively, north of Virginia City. An induced-polarization anomaly also was recognized in an alluvium-covered area north of the
RESOURCES INVESTIGATIONS

Cornwall Knob. Preliminary results of core drilling aimed at acquiring more data on the geophysical anomaly suggested that the large areas of bleached rock are underlain by rock that has undergone intense argillic alteration and that contains finely disseminated pyrite. Additional drilling was done in the Cornwall Knob and Washington Hill areas to obtain geologic information and to compare geochemical data from depth with that obtained at the surface.

Structure of volcanic rocks, Goldfield

Detailed geologic mapping of volcanic rocks and associated intrusive rocks in the Goldfield district (loc. 2) by R. P. Ashley revealed a complex fault pattern that cannot be explained easily as one set of concentric collapse features of a caldera, or even as an asymmetric collapse followed by partial resurgence. Features formed during one or two periods of collapse were apparently modified by a major east-west fracture zone on the south side of the area and later by westward tilting and north- to northwest-trending basin-and-range faulting. Although some collapse may have followed both the early latitic and rhyolitic eruption cycles, most of the collapse features now visible formed after eruption of the late andesitic and dacitic pyroclastic materials that now occur in the eastern, southeastern, and southern parts of the area. Almost all of the ore deposits of the district are along fault systems that probably represent the margins of the oldest collapse area. The unique complexity of these particular fault systems may be the result of repeated movements produced by later structural events.

Heavy-metals potential at Round Mountain

The gold-bearing Tertiary rhyolite at Round Mountain, Nye County (loc. 3), long considered an intrusive rock, is a welded ash-flow tuff, according to D. R. Shawe and F. G. Poole. Geologic mapping at a scale of 1:15,840 indicates that this rock lies nearly flat upon Mesozoic granite and Ordovician sedimentary rocks. Earlier mining must have penetrated close to the contact between rhyolite and Ordovician rocks. The Ordovician rocks produced some gold and silver nearby, and therefore it seems possible that they are mineralized beneath the rich gold-bearing veins at Round Mountain.

Structural control of ore deposition, Gold Acres

Studies by C. T. Wrucke and T. J. Armbrustmacher show that the open-pit mine at Gold Acres, Lander County (loc. 4), lies in the breccia zone of the Roberts Mountains thrust fault and that many steep and flat-lying faults of probable Tertiary age cut the thrust in the mineralized area. Concentrations of gold occur (1) along the faults, (2) in tabular and lensoid blocks of sedimentary rocks dragged into the breccia zone during thrusting, and (3) in fractured felsic dikes that cut thrust blocks. Mineralized blocks in the breccia zone are from both the lower-plate Roberts Mountains Formation (Silurian) and the upper-plate Slaven Chert (Devonian). The occurrence of gold along faults and in several types of shattered rocks indicates that structural controls probably were more significant than lithology in the deposition of gold at Gold Acres.

Geochemical studies in Cortez-Buckhorn area

Regional geochemical maps of the Cortez-Buckhorn area, Eureka and Lander Counties (loc. 5), compiled by J. D. Wells and J. E. Elliott from the results of analyses on about 910 samples, show that carbonate rocks below the Roberts Mountains thrust fault contain stronger anomalies than the cherts above the thrust. The metals that commonly occur in anomalous amounts with gold and silver are mercury, arsenic, antimony, copper, lead, and zinc. Molybdenum and tellurium anomalies are also present. The strongest anomalies in either upper or lower plate rocks are near granitic igneous rock masses and are localized along fracture systems, commonly in association with areas of wallrock alteration. Mineralization does not appear to be selectively associated with the Roberts Mountains thrust.

Geochemical studies at Copper Canyon

Detailed study by T. G. Theodore of the Copper Canyon copper-gold deposit southwest of Battle Mountain in Lander County (loc. 6), shows that a broad pyritic halo surrounds the Copper Canyon deposit. Deep core drilling by the U.S. Geological Survey at Iron Canyon, northeast of Copper Canyon, has provided geochemical information on the pyritic alteration in the third dimension. The fact that a drill hole 2,672 feet deep and collared within the halo penetrated altered rocks only to a depth of about 1,100 feet sug-
suggests that the halo dips in toward the center of metal-
\[\text{lization. The drill hole was entirely in chert and argil}
\[\text{lite of the Scott Canyon Formation (Lower or Middle }
\[\text{Cambrian (?)). In the altered drill core, copper, bar-
\[\text{ium, manganese, zinc, chromium, nickel, and to a lesser }
\[\text{extent lead and molybdenum, are several times greater }
\[\text{than background. Barium and manganese are the ele-
\[\text{ments that best reflect the extent of altered rock.}
\]

**Stratigraphy, structure, and mineral deposits, Tuscarora Mountains**

Geologic mapping by R. R. Coats in the Mount Blitzen quadrangle, west of Tuscarora (loc. 7), shows that the Tuscarora Mountains at this latitude are formed of a horst of Paleozoic rocks of the western assemblage, overlain by Tertiary ignimbrites and andesite, and intruded by a quartz diorite stock. The first reliable information on the age of the Paleozoic rocks resulted from the determination by J. W. Huddle of Ordovician or possibly Silurian conodonts from a thin limestone lens. The Paleozoic rocks are lithologically like the Seetoya sequence in the Independence Range across Independence Valley to the east of Tuscarora.

The downthrown blocks on both sides of the horst have deposits of gold, silver, and mercury having a crudely zoned distribution. Small, pocket high-grade deposits of gold and silver have been mined in the horst. Small amounts of mercury and silver have been produced in the downthrown block west of the horst, and substantial amounts of gold and silver as well as a little mercury have been mined in the Tuscarora district, east of the horst.

**Geology and chemistry of Carlin gold deposit**

Geologic mapping by A. S. Radtke in and around the Carlin gold mine in Eureka County (loc. 8), shows that the gold mineralization is strongly influenced by structural controls. Premineralization faults and shear zones, and the intersections of these features, provided channels for ore solutions. The amount and extent of shattering in the Roberts Mountains Formation, the host rock for the gold deposit, controlled the lateral movement of the solutions outward from the main structures.

Three distinct types of carbonaceous materials are present in the Roberts Mountains Formation. These include an activated carbon, mixtures of high molecular weight hydrocarbons, and an organic acid similar to humic acid. All three are important in controlling deposition of gold from hydrothermal solutions. Acid ore solutions carrying gold, probably as a chloride complex, dissolved out carbonate and introduced silica and pyrite plus minor amounts of other sulfides and alumina. Gold complexes in the ore solution interacted with the carbonaceous materials, and humic acids removed the gold from solution and chemically bound it to the acid molecule. During late oxidation these compounds were decomposed and metallic gold was released.

**NORTH CAROLINA**

**Mineral deposits in central part of State**

Studies of the Carolina slate belt in central North Carolina (locality 1, index map) by A. A. Stromquist indicate that the Silver Hill-Gold Hill fault-shear zone is several miles wide and can be traced for many miles, probably northeast into Virginia and southwest into South Carolina. East of this fault-shear zone, volcanic-sedimentary rocks of low-grade greenschist facies show both broad and minor open folds. West of the fault-shear zone, volcanic-sedimentary rocks are cut by intrusive rocks and are more highly metamorphosed, disturbed, and weathered than those to the east.

The gold and sulfide deposits are structurally controlled and to some degree are related to specific rock types. The main mining districts—Conrad Hill, Silver Hill, Gold Hill, and Georgeville—are west of the Silver Hill fault and are enclosed in sericitized and chloritized schists derived from sheared interbedded felsic and mafic volcanic-sedimentary rocks. The deposits east of the Silver Hill-Gold Hill shear zone are in smaller shears that cut a sequence of volcanic-sedimentary rocks; in this area, the deposits are richest where the shear zone cuts rhyolitic layers or tuffaceous mudstone.

**Gold deposits, Moore County**

Samples from 245 localities in road outcrops, 9 gold mines, and 6 pyrophyllite mines collected by F. G. Lessure during reconnaissance geochemical studies in Moore County, south-central North Carolina (loc. 2), were analyzed for gold. The area studied was 18 miles long and 6 miles wide. Eighty samples from the gold mines contained 0.15 to 0.71 ppm gold, and 46 samples from the pyrophyllite mines, a trace to 0.12 ppm gold. The highest analysis, of thin quartz veins in a roadcut, was 2.4 ppm gold, and only 8 samples, all from gold mines or prospects, contained more than 1 ppm gold.
The entire area seems to show a low-grade gold anomaly. Locally, concentrations of gold in sheared felsic tuff and thin seams of vein quartz were rich enough to encourage small-scale mining in the late 19th century. Thick quartz veins are abundant in the area but generally contain little or no gold. Trace amounts of gold in the pyrophyllite zones produced small placer deposits which were prospected before the discovery of the pyrophyllite. Total production from Moore County is unknown but probably small.

OREGON

Geology of the Sixes River drainage

The Sixes River enters the Pacific Ocean just north of Cape Blanco (locality 1, index map) and directly east of the most extensive and highest concentration of gold and other heavy minerals found thus far on the Oregon Continental Shelf. The river appears to be a major source of heavy minerals, and therefore a detailed study of its drainage basin is being made by S. M. Boggs, Jr., and E. M. Baldwin (both of University of Oregon) through a research contract with the University of Oregon at Eugene.

Bedrock in the drainage area was mapped, and stream sediment was sampled in detail and analyzed chemically and petrographically. The major source rock for gold appears to be the Galice Formation (Jurassic) and associated small intrusive bodies. The Galice Formation consists mainly of slaty to phyllitic mudstone, siltstone, and sandstone. The intrusives, emplaced during the Late Jurassic Nevadan orogeny, are mainly diorite and quartz diorite. The Galice, where it is free of intrusives, and the larger masses of dioritic intrusive rock are less important gold sources. Conglomerate of Cretaceous age, which overlies the Galice Formation and associated intrusives, is apparently not a major contributor of second-cycle gold. Rocks of probable post-Nevadan Jurassic age, the Colebrooke Schist and associated ultramafic rocks, and Cretaceous and Tertiary shales and sandstones are minor to negligible contributors of gold.

SOUTH DAKOTA

Gold deposits in Precambrian rocks, northern Black Hills

Geologic mapping of Precambrian rocks in the Rochford district, 20 miles south of Lead (locality 1, index map), was nearly completed by R. W. Bayley. The principal structure is a refolded anticline in which the oldest rocks exposed are probably Ellison Formation of Hosted and Wright (1923)1, a quartzite unit that overlies the gold-bearing Homestake Formation of Hosted and Wright (1923) at Lead. Three rock units resembling the Homestake lie above the Ellison at Rochford; one, close to the quartzite in a slate sequence, may correlate with the Northwestern Formation of Hosted and Wright (1923) at Lead, and two are associated with graphitic schist and ellipsoidal greenstone. The schist, greenstone, and chert-cummingtonite rocks of the Homestake-like units collectively could be correlative with the vaguely defined Flag Rock Formation of Dodge (1942)2 at Lead. As at Lead, the chert-cummingtonite rock is gold bearing locally. Also as at Lead, the gold seems to prefer plunging anticlines, but there are a few exceptions: A few mineralized localities contain abundant pyrrhotite and are therefore anomalously magnetic.

The principal structure at Rochford was previously interpreted as an upside-down syncline, but the new detailed mapping shows it to be an anticline similar to those at Lead and involving the same rocks, complicated by refolding. It offers several exploration possibilities—for example, most mining to date had been in the uppermost chert-cummingtonite unit, but it now seems probable that one or two similar units lie stratigraphically below and have not been tested. Also, a dozen large mildly mineralized plunging anticlines should be tested to depth, as they are in every way similar to the Homestake structures.

ATLANTIC COASTAL PLAIN AND TRIASSIC BASINS

Reconnaissance sampling of Atlantic Coastal Plain sedimentary rocks was done by J. P. Minard along the

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2 See note opposite page A1 for explanation of reference notations.
inner edge of the coastal plain from Alabama north to New Jersey, and rocks of the Triassic basins were very sparsely sampled from South Carolina to Massachusetts. Detailed sampling was done in the inner coastal plain of northern South Carolina and southern North Carolina. The Triassic was sampled in detail in the Farmington basin of northern North Carolina, in parts of southern North Carolina near Mt. Gilead, and in northern Virginia.

Several streams draining an upland area of 15 sq mi on the inner coastal plain near Jefferson, S.C., yield appreciable gold in panned samples; as many as 50 particles of gold, ranging from silt to very coarse sand size, were obtained in concentrate from a single pan. Samples obtained from sand and gravel layers in the coastal plain sediments, both in outcrop and from auger holes, also have yielded gold.

Triassic sandstone and conglomerate in the Mt. Gilead area, North Carolina, contain from 0.10 to more than 2.0 ppm Au. Streams in the area yield particles of gold in panned concentrates, although they are not as abundant as in concentrates from the Jefferson, S.C. area. Coastal plain sediments have as much as 2.0 ppm Au. Traces of gold were found in conglomerate in a small Triassic basin at Farmington, N.C., but samples of quartz and schist from a small area in the center of the basin have higher gold contents, from 1.0 to 12 ppm Au.

The Triassic rocks of southern Pennsylvania were not examined in detail, but three of four samples of siltstone, sandstone, and diabase had gold contents of as much as 4.5 ppm. These rocks are to be further investigated.

Five of seven samples of Triassic diabase near Leesburg, Va., showed detectable amounts of platinum minerals, and several more samples are being analyzed. Several zinc anomalies, containing as much as 7,000 ppm (0.7 percent), have been found along the border fault zone of the Triassic basin north of Leesburg.

PROCESSES AND METHODS OF STUDY

Fluvial transport of fine-grained gold

Several years of work by J. C. Antweiler and J. D. Love on fine-grained gold-bearing alluvial sediments along major rivers in and adjacent to northwestern Wyoming demonstrated that very small amounts of gold can be transported and deposited for hundreds of miles along major river systems. Under highly favorable conditions, gold can be deposited in commercial quantities as demonstrated by past exploitation of placer along the Snake River in Idaho. A good example is an occurrence of gold in fine-grained sand and silt near American Falls, Idaho. This gold was almost certainly derived from the Harebell Formation and F'yon Conglomerate in northwestern Wyoming, 250 miles upstream. Even though individual gold particles average less than 5 µg in weight and less than 100 µm in diameter, concentrations worth as much as $1.00 per cu yd have been found.

Counter-current elutriator as a gold concentrator

A counter-current elutriator was calibrated by H. A. Tourtelot in terms of total discharge and distribution of velocities within the elutriator as compared to the fall velocities of different sized particles of gold. The results indicate that the elutriator is probably a highly effective tool for rapid determination of the gold content of unconsolidated sediments or disaggregated sedimentary rocks. Because only water is used, the method is cheaper, faster, and more convenient than other methods of separation such as heavy liquids. If material coarser than 2 mm is removed from a sample and the remainder divided into fractions of four sizes (coarser than 0.5 mm, coarser than 0.15 mm, coarser than 0.061 mm, and finer than 0.061 mm) the gold in each fraction can be removed in a matter of minutes. If the elutriator is of an appropriate size for the mass of the fractions, the time depends chiefly on the handling of materials rather than the settling of the gold. Only gold coarser than 0.024 mm will be removed from the finest fractions. These size boundaries are suggested because the fall velocity of gold is about 30 percent higher than quartz in the two coarse fractions and 50 percent higher in the two fine fractions. The greater difference in fall velocity for the fine fractions is desirable because gold in these sizes tends to be flaky. The size of elutriator that would be effective has no evident theoretical limit, and the process might even be adaptable to some commercial operations. Further experimental work is underway to explore these indications.

Fluid inclusions in ore deposits

Fluid inclusions in transparent minerals are being studied by J. T. Nash in order to gather information on the nature of fluids coexisting with minerals in heavy metal deposits. Reconnaissance studies made in several mining districts served to place limits on temperatures of formation and salinity of the ore fluids. Gangue minerals associated with the fine-grained gold at the Cortex deposit, Eureka County, Nev., and the Gold Acres deposit, Lander County, Nev., generally contain fluid inclusions too small for heating and freezing stage measurements; however, some measurements and many estimates made to date are in the range 160°–230°C, with salinities equivalent to about 6 percent NaCl. In the Bodie district, Mono County, Calif., and at Round Mountain, Nye County, Nev.,...
lode deposits of gold associated with quartz and adularia appear to have formed from very slightly saline solutions at about 250°C. Fluid inclusions in quartz from base metal veins in the Tenabo district, Lander County, Nev., and Rosita district, Custer County, Colo., homogenize over the range 350°-175°C and have salinities equivalent from 33 to 0.2 wt percent NaCl. The fluid-inclusion data suggest that some deposits formed under decreasing temperatures, whereas others formed at relatively uniform temperatures. Some localities, such as Rosita, Round Mountain, and Tenabo show evidence for boiling with consequent wide variation in salinity. Boiling or dilution with meteoric water appears to have caused mineral deposition in several localities.

OTHER COMMODITIES
BASE AND FERROUS METALS
Alaska

_Eastern Seward Peninsula._—Investigations in the Candle 1:250,000-scale quadrangle in eastern Seward Peninsula of Alaska by T. P. Miller and R. L. Elliott resulted in the discovery of two large mineralized areas near Granite Mountain (locality 1, index map). The larger of the two areas is along Quartz Creek west of Granite Mountain where numerous occurrences of sulfides of lead, silver, and zinc were found over a length of 18 miles. The sulfide minerals are associated with tourmaline, and the deposits have above-background tin values; they resemble deposits of tin and base metal sulfides found farther west. The other mineralized area is east of Granite Mountain in the headwater basin of the upper Peace River, where minerals of molybdenum, silver, bismuth, lead, and uranium are associated with an alkaline intrusive stock.

_Alanada Range._—Deposits of massive, fine-grained copper, silver, and zinc sulfides were discovered 2 miles north of Shellabarger Pass in the Alaska Range (Talkeetna C-6 quadrangle) (loc. 2) in 1967 by B. L. Reed and R. L. Elliott and were mapped and sampled in more detail by Reed and G. D. Eberlein in 1968. The deposits are either bedding replacements of calcareous units in a sequence of chert, argillite, and limestone that is cut by diabasic dikes, or are fracture fillings in chert. The dominant minerals are pyrite, chalcopyrite, sphalerite, arsenopyrite and sulfosalts. The largest body exposed is slightly more than 100 feet long and at least 17 feet thick. Massive sulfides crop out 1,000 feet south and also 800 feet west of the main showings. These deposits are of a new type and are in a different geologic setting than the previously reported lead-zinc-silver deposits south of Farewell, which suggests that the Shellabarger Pass area also warrants further attention by prospectors and exploration geologists.

_Colorado._—According to F. A. Hildebrand, a small, but high-grade occurrence of rare-earth-bearing apatite and molybdenite, was found in a short dikelike body of coarse breccia in the Silver Cliff-Rosita mining district, Custer County (locality 1, index map). The minerals occur in the matrix of the breccia, and consist principally of titanium-free magnetite and r-oderate amounts of pyrite, some molybdenite, rare-earth apatite, and other minerals. This matrix cements fragments and boulders of andesitic rocks. The molybdenite, which is partly altered to powellite, is generally associated with thin carbonate veins composed mainly of brown ankerite and siderite. The rare-earth-bearing apatite, which occurs as stubby and acicular crystals ⅛ to more than 2 inches in length, is easily identified by an unusual bright-orange fluorescence in short-wave ultraviolet light. The apatite consistently contains about 3.4 percent lanthanum group elements and 0.4 percent yttrium group elements, but only 0.5 percent silicon. Although the deposit is small it may have economic importance because of the relatively high content of lanthanides.
**Michigan**

A ground magnetometer survey by W. F. Cannon in an area of unconsolidated deposits that overlie the Negaunee Iron-Formation in the Greenwood quadrangle, Marquette County (locality 1, index map), revealed four distinct maxima of as much as 20,000 gammas within a broad anomaly previously known from aeromagnetic surveying. The anomaly is located in secs. 22, 23, and 24, T. 47 N., R. 28 W. Three of the magnetic maxima are known to overlie hard iron-ore bodies, but the fourth, near the common corner of secs. 14, 15, 22, and 23, is in an unprospected area, and may be related to a similar but as yet undiscovered ore body.

**Tennessee and Kentucky**

*Depth of lead-zinc ore deposition in Tennessee.*—Compaction features in the Lower Ordovician carbonate rocks of the East Tennessee zinc district studied by Helmut Wedow, Jr., (U.S. Geological Survey) and W. T. Hill (New Jersey Zinc Co.) added independent evidence to the hypothesis that the ore deposits of the southern Appalachian Valley were formed at depths of less than 1,000 feet in collapse breccias and cave fillings that are related to an early Middle Ordovician paleoaquifer. Sigmoidally contorted desiccation-crack fillings in fine-grained dolomite country rock show that the ore-bearing strata were compacted as much as 40 to 50 percent on burial to depths of 10,000 feet or more by the end of the Paleozoic era. In contrast, data developed from marker beds within the collapse breccias indicate that these strata were compacted only 25 to 30 percent after brecciation, and hence were brecciated at depths of less than 1,000 feet—depths that could have existed only during the early part of Middle Ordovician time.

*Lead and zinc in central Tennessee and central Kentucky.*—Surface and subsurface stratigraphic and structural studies in the Central Tennessee and Central Kentucky mining districts by A. V. Heyl and his co-workers strongly suggested that if large commercial mineral deposits exist at depth, the ores will probably be disseminated in the more permeable beds of the Knox Dolomite (Lower Ordovician portion) and will contain comparable mineralogic assemblages. The Central Tennessee district is probably more favorable for such large deep deposits, because fewer large faults cut through the Nashville dome in Tennessee than through the Lexington dome in Kentucky, Thus, there were more possibilities for tapping the ore solutions in the Knox Dolomite strata of the Nashville dome than in the Lexington dome.

In both districts the most promising areas of probable ore occurrence are in localities where only a few veins of rich ore extend to the surface, and where sharp monoclines are parallel to the known faults. Such monoclines may indicate faults in the lower formations that do not extend to the surface. Such fault's at depth could have provided conduits from which the ore-depositing solutions spread out into permeable beds. Such favorable areas exist (1) in the area just north of Nashville, (2) near Murfreesboro, (3) near Lebanon, (4) and between Gordonsville and Baxter, and all in Tennessee. Similarly, the most favorable areas in the Central Kentucky district lie (1) near Gratz, where some deep drilling has shown that the Knox Dolomite is permeable and at least locally prepared by solutions, (2) northeast of Frankfort, (3) between Lexington and Millersburg northwest of the West Hickman fault zone along the crest of the Cincinnati arch, (4) near Mortons Mills in Fayette County, and (5) west of the Kentucky River fault zone in Woodford, Jessamine, Mercer, Boyle, and Garrard Counties. The Central Kentucky district is concentrically zoned; thus the most favorable area for the occurrence of lead and zinc ore bodies is in the downward-expanding zone that contains barite, galena, and sphalerite.

Detailed studies indicated that the Central Kentucky and Central Tennessee districts are comparable in mineralogy and in content of minor elements. Thus the galenas from both districts have little silver or other minor elements; in contrast, much of the sphalerite is enriched in mercury, cadmium, germanium, and gallium (in amounts potentially quite valuable as byproducts), and much of the barite is enriched in strontium.

**Utah**

E. W. Roedder reported that some bubble-bearing fluid inclusions in quartz-molybdenite veins from a porphyry copper deposit at Bingham Canyon, Utah, show high salt concentrations and high homogenization temperatures. Many of these inclusions are second-

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ary, formed by the healing of postmineralization fractures, but some may be primary, having been filled during deposition of the vein minerals. Both types of inclusions indicate the former presence of fluids containing 45 percent NaCl, 15 percent KCl, and 40 percent H_2O. In addition, minor amounts of other mainly unidentified constituents may also have been present. The homogenization temperatures, which are the temperatures at which a single gas or fluid phase appears in the inclusions, are unexpectedly high, averaging 650°C but ranging upward to 725°C. Salt concentrations and homogenization temperatures are much lower in fluid inclusions in minerals associated with the replacement lead-zinc ore bodies in areas peripheral to the central, disseminated copper ore body.

It is believed that these data will eventually be helpful in understanding the circulation patterns of ore-solution movement during ore deposition.

Wisconsin
Detailed geologic mapping by W. S. West delineated an extensive area of previously undescribed lead, zinc, and iron sulfide mineralization and associated rock alteration of the Platteville, Decorah, and Galena Formations in Grant County (locality 1, index map). This area is a westward continuation of a zone of lead and zinc mineralization that was recently recognized in the Pigeon Creek drainage basin. The mineralized localities discovered during the reconnaissance studies indicate that a virtually continuous east-trending belt of lead and zinc occurrences and small deposits extends across the Hurricane quadrangle from the Pigeon Creek locality in the Lancaster quadrangle to a point west of Beetown in the Beetown quadrangle. These discoveries greatly enlarge and more clearly define areas that are favorable for prospecting by mining companies and other interested persons in the northwestern part of the Upper Mississippi Valley mining district.

Ore-depositing fluids
Porphyry copper deposits.—A model was developed by D. E. White and L. J. P. Muffler to account for porphyry-copper mineralization. The model is based (1) on data on temperatures and compositions of ore fluids derived from study of fluid inclusions by E. W. Roedder; (2) on recent studies by others of the ratios D/H and O^{16}/O^{18} in alteration clays, quartz, and micas which strongly support major involvement of meteoric water in the mineralization; and (3) on data from studies of active thermal systems by White and Muffler. White and Muffler's data point strongly to Na-Ca-Cl brines, probably dominantly of origin external to the porphyry intrusions, and perhaps metal rich but sulfide poor, as the ore-transporting fluid at depth. Convectively circulating brine can dissolve metals from various sources, but major sources of copper and other metals may have been in specific porphyry bodies or in their larger magmatic hearths, because of their higher temperatures and perhaps higher initial metal contents. The circulating brine was an effective agent in redistributing and locally concentrating the metals. Sulfur is dominantly of magmatic origin. The dense circulating brine is probably overlain by one or more convection cells of dilute Na-K-Cl-HCO_3-SO_4waters almost wholly of meteoric origin, typical of the waters discharged in surface springs of Yellowstone Park, Steamboat Springs, Nevada, and elsewhere.

Fluid inclusions in lead-zinc deposits.—Fluid inclusions in suites of samples from the large lead-zinc deposits in carbonate reef rocks at Pine Point, Northwest Territories, Canada, and from the large deposit in Cambrian sandstones at Laisvall, Sweden, were examined by E. W. Roedder. These studies were made to gain a better understanding of the geologic processes forming similar stratiform, Mississippi Valley-type ores in the United States. The ores in both deposits formed from exceedingly saline brines, with probably over 30 wt percent salts. At Pine Point, temperatures of these fluids were in the range 50° to 90°C, somewhat lower than in most similar deposits in the United States. At Laisvall, temperatures were generally in the range 150° to 185°C, with only a very few at higher temperatures, up to a maximum of 223°C. These data serve to eliminate some of the theories of origin involving fresh or sea water that have been proposed for such deposits, and place some restrictions on the possible mechanisms and modes of circulation of the ore-forming fluids.

Light Metals and Industrial Minerals
Phosphate deposits
Economic phosphate deposits along the Atlantic Coastal Plain of the United States are in rocks of middle Miocene age and in younger rocks that derived much or all of their phosphate by reworking of Miocene rocks. The locations of the deposits are considered
by J. B. Cathcart (r2058) to be in part structurally controlled. Except for those of the land-pebble district of Florida, all are along the north or east flanks of positive areas that were rising at the time of deposition, suggesting that phosphate precipitated in areas along the coast where cool southward-moving phosphate-rich waters were diverted eastward and mixed with warmer waters. Tertiary rocks of the Gulf Coastal Plain contain only minor amounts of phosphate, possibly owing to the rising Floridian Plateau which acted as a very large positive area that diverted the phosphate-bearing waters southward and out to sea.

The phosphate deposits of North Carolina, South Carolina, north Florida-south Georgia, and the central peninsula of Florida, are similar in gross features but different in detail. Chemical composition, size distribution of phosphate particles, clay mineralogy, and the intensity of leaching which formed aluminum phosphate minerals seem to vary systematically from north to south. For example, near-surface apatite in North Carolina is relatively unaltered, in South Carolina it is only slightly altered, in north Florida-south Georgia there are some aluminum phosphate minerals, and in the Florida deposits of the land-pebble phosphate district apatite is altered by lateritic weathering. X-ray diffraction studies of phosphate minerals from these areas also indicated a slight variation in cell dimensions from north to south, which is thought to be caused by a variation in the CO₂-P₂O₅ ratio of the apatite. Variation in the mineralogic composition of the diluting materials (clay minerals, carbonate minerals, iron minerals, organic material, and quartz) suggests that the southerly deposits are more altered and re-worked than the northerly deposits.

Phosphatic rocks continue to be identified in other formations or parts of the country where they were previously unknown. In the course of regional geologic mapping, K. B. Ketner noted that Permian siltstone, limestone, and chert beds in the Adobe Range, Elko County, Nev. (T. 34 N., R. 54 E., and T. 38 N., R. 56 E.), are significantly phosphatic. The phosphate resembles that of the Phosphoria Formation, consisting of rounded pellets, irregular grains, and fillings of spicules and pelecypods. The phosphate content per unit area exceeds that of the Phosphoria Formation, but the phosphate is diluted with carbonate and quartz silt and is therefore not likely to be of immediate economic value. In northern Nye County and southern Eureka County, C. L. Rogers, F. J. Kleinhampl, J. I. Ziony, and Walter Danilchik found concentrations of phosphate in Cambrian, Ordovician, Silurian, and Permian (?) age rocks that were deposited in the eugeosynclinal western, transitional, and miogeosynclinal (eastern) facies. The phosphate occurs chiefly in beds that are near lithologic breaks in the stratigraphic section that may also be formalional boundaries. Grades of beds several inches to a few feet thick range from about 2 to 18 percent P₂O₅. The richest and thickest beds are in carbonate sequences.

**Potash, salt, and other evaporite deposits**

Halite rock in many marine salt deposits has thin beds characterized by a high content of anhydrite, clay, or sapropel. These beds, which are usually less than 1 inch thick, probably represent a seasonal influx of fresher water or temperature change. Such beds are also well defined in the halite rocks of the Paradox basin of southeast Utah and southwest Colorado. By measuring numerous sections from underground exposures of potash-rich zones in the Texas Gulf Sulphur Corp. mine near Moab, Utah, R. J. Hite was able to establish the detailed stratigraphy of the Salt-5 ore zone. Readily identifiable marker units within this sequence, based on band spacing, pigmentation, or mineralogy, allowed precise location of stratigraphic position within the potash ore zone at almost any mine exposure, and were an invaluable aid in demonstrating solution of the top of the halite zone as well as lateral variations in mineralogy or trace-element distribution in the ore zone. Marker units have also been very useful in mining operations where it is important to know the position of advancing faces within the ore zone at all times.

The bromine content of 657 samples of halite from 26 of the 29 depositional cycles in the Paradox Member of the Hermosa Formation (Pennsylvanian) in two wells in the Paradox basin was determined by O. B. Raup and H. L. Groves, Jr. Bromine was determined by X-ray fluorescence from cuttings collected at 10-foot intervals, and the values obtained range from 30 to 316 ppm. Stratigraphic profiles constructed from these analyses clearly show large-scale basin-wide salinity cycles. Periods of influx with reflux, as well as periods of influx with little or no reflux are demonstrated. The well located closer to the basin center has a higher average bromine content than the well located closer to the shelf, thus suggesting a salinity gradient within the halite facies. An important aspect of this study is that these profiles were constructed from data obtained from cuttings, not cores, and it is demonstrated that they closely resemble profiles obtained from cores. The profiles are not as regular as those obtained from core material because the samples were taken from a greater stratigraphic interval and are not the accurate composites of the 10-foot interval nor free of

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8 See note opposite page A1 for explanation of reference notations.
contamination—but they provide usable information in areas devoid of other data. This allows a much broader regional study of paleosalinities than is possible from core samples which are generally unavailable.

Evaporite cycles in the Paradox basin were probably due to periodic fluctuations in sea level. Each complete evaporite cycle consists of a transgressive and a regressive phase bounded by a disconformity. These evaporites grade shelfward into predominately carbonate facies. As noted by R. J. Hite, water escaping from the evaporite basin may have affected carbonate sedimentation on the adjacent shelf to the southwest. For example, higher sea levels and a resulting increase in reflux would have carried larger volumes of toxic brines onto the shelf and created unfavorable conditions for life and deposition of biogenic carbonates over an enlarged area. During maximum reflux, reducing conditions apparently allowed black sapropelic shales to form in areas where normal marine deposits such as limestone were previously deposited. Only during periods of low sea level, when little or no water refluxed, were shelf conditions optimum for growth of algal bank carbonates. Inasmuch as the bromine distribution in halite is an index of basin reflux, cycles favorable for the development of algal carbonate facies on the shelf may be predicted. Algal carbonate facies in many marine evaporite basins are major sources of petroleum, and bromine geochemistry may gain an unexpected use in petroleum exploration.

**Borates**

A new study of the mineralogy of the Miocene Kramer borate deposit at Boron, Kern County, Calif., was recently completed by Vincent Morgan (U.S. Borax and Chemical Co.) and R. C. Erd. Several minerals new to this deposit were found: barytocalcite, garrelsite, hypersthene, natrojarosite, natrolite, sideronatrite, and witherite. This is the second occurrence of garrelsite which heretofore was known only from the Green River Formation (Eocene) in Utah. A possible new mineral, a yellow sulfoxide of arsenic, was found as an alteration product of realgar.

A new interpretation of the origin of the Kramer ore body by W. C. Smith retains the basic model of H. S. Gale who postulated a lake that received both fresh stream waters containing clay and thermal spring waters containing sodium borate, but adds the concept that as many as three distinct layers of lake waters existed and that they were stratified according to density. The upper layer consisted of inflowing fresh water that spread widely over the lake surface because of its low density. Thin beds of dolomitic claystone were deposited from this layer which introduced calcium and magnesium in addition to fine-grained detrital material. After evaporation of the surface layer, continued evaporation or cooling of the borate-rich waters beneath it caused precipitation of borax. A basal layer of water was formed where warm, very dense sodium borate-rich spring waters flowed into the deepest parts of the basin. Because the solubility of sodium borate decreases so markedly with a decrease in temperature, mixing of this layer and the overlying colder lake water at the interface caused precipitation of additional borax.

Sodium borate also occurs in Searles Lake, Calif. A byproduct of the study of that Pleistocene borate deposit was the discovery by Sadao Matsuo Irving Friedman, and G. I. Smith that the saline layers of Wisconsin age provide two criteria for estimating crystallization temperatures of the saline minerals. Published phase data, when applied to the primary mineral assemblages, place approximate limits on possible crystallization temperatures. Variations in the ratios of the hydrogen and deuterium isotopes in certain coexisting pairs of saline minerals also provide temperature estimates. Crystallization temperatures of the saline units reflect Pleistocene interpluvial (and interglacial) climates which can be compared with those of the present. (Average monthly temperatures today range from 7° to 32°C.) Solubility data shows that during times of low evaporation or in lakes deeper than about 10 m, trona probably crystallized in the winter; in shallower lakes, it crystallized during winter and summer. Burkeite and halite crystallized from shallower lakes chiefly in summer. Average isotopic temperatures on seven superimposed layers of micritic Wisconsin age start below 0°C, increase systematically to about +15°C in the middle unit, then fall below 0°C again; the lower temperatures probably occurred from crystals formed in winter, whereas the higher temperatures come from crystals formed during more than one season. The stratigraphic distribution of burkeite and halite in these layers suggest summer or mean annual temperatures above 20°C for the middle two, below 20°C for some or all of the others. These data suggest that some interpluvial climates were substantially cooler than present climates.

Deposits containing another borate mineral, colemanite \( \text{Ca}_2\text{B}_2\text{O}_5 \cdot \text{H}_2\text{O} \), were studied by B. M. Madsen in a core from a nonmarine (?) upper Cenozoic evaporite section in the Mojave Desert, near Hector, Calif. The core is chiefly anhydrite and clastic rock but also contains an appreciable amount of colemanite and...
Chemical deposits associated with oil shales

The stratigraphic and mineralogical continuity of a dawsonite-rich oil shale zone in the lower part of the Parachute Creek Member of the lacustrine Green River Formation (Eocene) are being studied by D. A. Brobst from exposures in the vicinity of lower Parachute Creek, Rio Blanco County, Colo. The dawsonite is estimated to constitute as much as 25 percent of some oil shale beds in a zone at least 50 feet thick where it emerges from the subsurface. About 2 miles updip and shoreward along the north rim of the Parachute Creek basin, the oil shale zone thins to less than 10 feet and the dawsonite content is much lower. The zone can be traced accurately because of a nearly continuously exposed altered tuff bed. The tuff bed contains varying amounts of analcime, quartz, a mixture of feldspars, and dawsonite. Analcime and dawsonite coexist in samples of both tuff and oil shale.

Halite and nahcolite form an evaporite facies in subsurface portions of the oil shales of the Green River Formation in the Piceance Basin. Studies by J. R. Dyni, R. J. Hite, and O. B. Raup of samples from one bore hole drilled near the depocenter of the basin (where the halite deposits are thickest) show that the bromine content of 169 samples of halite from a 450-foot thick section of halite and associated rocks ranges from less than 39 ppm to as much as 182 ppm. The bromine content in halite increases progressively from the base to the top of this section. Because bromine is a salinity indicator, these data indicate a gradual increase in the salinity of the ancient lake waters. The few published data on the bromine content of other continental halite deposits suggest that the bromine content of the Green River halite is unusually high. Possible source rocks for the bromine include contemporaneous tuffaceous sediments and older marine evaporites.

Fluorite and zeolites

A sizable low-grade deposit of fluorite was found by R. A. Sheppard and A. J. Gude III (p. D69-D74)

in Pliocene lacustrine rocks near Rome, Malheur County, Oreg. The fluorite-bearing rocks include tuff, tuffaceous mudstone, and mudstone, and underlie an area of about 7 sq mi, chiefly between Crooked Creek and the Owyhee River. Fluorite occurs as submicroscopic, nearly spherical grains that are nonuniformly disseminated in the upper 60 feet of the lacustrine rocks. The content of fluorite is generally less than 5 percent, but as much as 16 percent was found in the lower part of a conspicuous zeolitic tuff. The fluorite probably formed during diagenesis in sediments that had been deposited in an alkaline, saline lake.

Zeolites, potassium feldspar, silica minerals, and clay minerals of diagenetic origin were also found by R. A. Sheppard and A. J. Gude III, in altered silicic tuffs interbedded in lacustrine rocks of the Barstow Formation (Miocene), Mud Hills, San Bernardino County, Calif. The zeolites are chiefly analcime and clinoptilolite, although local concentrations of chabazite, erionite, mordenite, and phillipsite have been found. Two or more zeolites generally occur in a bed, but some beds are monomineralic. Zeolites, except analcime, are locally associated with relict glass. Petrographic study of these rocks showed that the zeolites, except analcime, formed early during diagenesis by solution of shards and then precipitation of the zeolites from solution. Analcime formed later by the reaction of the alkalic, silicic zeolites. Potassium feldspar formed still later by reaction of the analcime and the alkalic, silicic zeolites with highly saline interstitial water. Apparently, neither analcime nor potassium feldspar forms directly from silicic glass in tuffs of saline lake deposits.

Another zeolite, laumontite, was identified in Miocene rocks at two new localities in the central Coast Ranges by B. M. Madsen and K. J. Murata. One is the Diablo Range on the east side of the San Andreas fault in an arkosic sandstone mapped by others as upper Miocene; the other is west of the San Andreas fault in the Santa Cruz Range in an arkosic sandstone mapped by others as upper Oligocene or Miocene. Laumontite is commonly reported from Cretaceous or Jurassic rocks of California, but there have been only two previous reports of laumontite from Tertiary rocks in California. Laumontite is generally regarded as a product of diagenesis of tuffaceous and arkosic sediments at great depths, but its distribution at these new localities is irregular and does not seem to reflect simply the depth of burial. The laumontite seems to occur in lenticular bodies where it replaced plagioclase of the arkosic sandstone. Similar arkosic sandstones lower in the section do not contain laumontite, although they must have been more deeply buried.

Clays

Laboratory and field studies by J. W. Hoston provided new chemical and mineralogical data for...
three major deposits of white silty clay in Pennsylvania. The Toland clay deposit, Cumberland County, derived by alteration of the Tomstown Formation, has an average composition of 6 percent quartz sand, 34 percent quartz silt, 65 percent kaolinite, and 5 percent illite. The Al₂O₃ and SiO₂ contents average about 20 percent and 70 percent, respectively. Although probably modified by later weathering, a hydrothermal origin is indicated by the presence of alunite and vertical changes in the Al₂O₃ and SiO₂ contents that are the opposite of those normally found in weathering profiles. The Kunkletown clay deposit, Monroe County, (D94-D105) is a residual deposit formed by weathering of the New Scotland Formation and Buttermilk Falls Limestone. It is composed of about 36 percent quartz silt, 55 percent kaolinite, and 5 percent illite. The Al₂O₃ content averages about 15 percent, and the SiO₂ content averages about 80 percent. A clay deposit that extends over parts of Blair and Centre Counties is also residual material derived by weathering of the Gestateburg Formation. Samples from this deposit are composed of approximately 40 percent quartz silt, 55 percent kaolinite, and 5 percent illite; the Al₂O₃ and SiO₂ contents average about 20 percent and 70 percent, respectively.

Additional studies by J. W. Hosterman of 38 samples of underclay and shale from the anthracite district of eastern Pennsylvania suggest that these coal-bearing sequences have been exposed to temperatures above 500°C. This is inferred from the consistent association, as shown by X-ray diffraction data, of 2M illite, pyrophyllite, and chlorite, and the absence of kaolinite.

A byproduct of geologic mapping in Greene County, Pa., is the finding by J. B. Roen and J. W. Hosterman that some of the clay and shale in the Pittsburgh, Waynesburg, Washington, and Greene Formations (upper Paleozoic) have economic potential. Six representative samples from these formations are of material suitable for the manufacture of common, face, and decorative brick, and two represent raw material that could be used in the production of lightweight aggregate.

Large fuller’s earth deposits occur in the Meigs-Attapulgus-Quincy district, Grady, Thomas, and Decatur Counties, Ga., and Gadsden County, Fla., in the Hawthorne Formation of Miocene age. S. H. Patterson showed that deposits of mining grade are restricted to an elongate structural depression called the Gulf trough. Attapulgite is the dominant clay mineral in some deposits in the southern part of the trough, and montmorillonite is very abundant in the northern part. All deposits contain considerable quantities of quartz sand impurities. Diatoms are very common in deposits in the northern part of the district and contribute to the low bulk density of the fuller’s earth, a desirable property for some products made from it.

Preliminary studies were made by R. W. Luce on the chemical mechanisms and kinetics of the weathering of feldspars at room temperatures to clay minerals or their precursors. The results of the studies suggest that the potassium of potassium feldspars is the preferentially leached ion in acid solution. Attenuated total-reflection infrared-absorption techniques are also being investigated for potential use in the characterization of surface phases or amorphous material on slightly weathered feldspars. These surface phases presumably are the first step in a continuing series of reactions that leads, within relatively short periods of geologic time, to total conversion of feldspars to clay minerals.

Vermiculite

A study of vermiculite resources by A. L. Bush indicates a need for increased emphasis on exploration. Inasmuch as the broad geologic relations essential to the development of deposits are so imperfectly understood, the prospects for successful exploration are difficult to evaluate. A statistical analysis of the size and grade distribution of the deposits might define the targets. The largest known deposit is in Montana. Scattered deposits in the inner Piedmont region of South Carolina constitute the second largest producing district in the United States and the third largest in the world. A recent compilation of major and minor deposits in that area by the South Carolina Division of Geology lists 122 occurrences. A substantial reserve exists in these deposits, and stained and fine-grained-flake vermiculite may increase the reserve significantly if new beneficiation techniques are developed.

Barite

The world reserves of barite at the end of 1968 were estimated by D. A. Brobst to be about 200 million tons, about half of which is in the United States. This world supply, however, will last only 20 years if production grows at the same rate in the next 20 years as it did in the last 20 when production rose from 1 to 4 million tons annually. At least 80 percent of the world’s barite is consumed in drilling mud for oil and gas wells, and the remainder is used largely in the chemical, glass, paint, and rubber industries. Because of the intensifying search for oil and gas, and the expanding industrialization of the world for a population that could double in the next 30 years, barite consumption probably will continue to rise.
About 25 percent of the world's reported reserves are in the economically significant bedded deposits of Nevada and Arkansas. Similar deposits have not yet been sought in many parts of the world, but possibilities for the discovery of additional new large high-grade bedded deposits are good. Geologic factors suggest that world barite production and reserves can be increased in the coming years.

Peat

Peat reserves of 66 undeveloped deposits which were investigated by C. C. Cameron in southeastern New York were estimated to be 11,500,000 short tons of air-dried peat, most of which is good quality reed-sedge type.

The close relation between fiber size and water-holding capacity, a chief factor of commercial quality, was demonstrated by tests on samples from the 66 deposits. This relationship is in accord with recent recommendations of the American Society for Testing Materials' Peat Committee that fiber size be the main basis for classification of peat; this was part of an effort to establish commercial quality standards for the very new and rapidly expanding nonfuel peat industry. Inasmuch as fiber size is related to the diagenesis of peat deposits, all geologic factors that affect diagenesis become tools meaningful to the peat industry for predicting the quality of unexploited deposits.

Semiquantitative spectrographic analysis for 33 elements were made of the ash fraction of peat from 43 of these 66 peat deposits. About half the deposits have anomalous amounts of certain elements, most of which reflect the geology of the depression walls and of the surrounding drainage basin. A fivefold classification of the basins of accumulation, originally applied to deposits in the highlands of northeastern Pennsylvania and based on regional geology and physiography, was found to apply to lowland as well as highland deposits in New York. The same principles may be applicable to the wide variety of deposits in other regions.

Titaniferous sandstone

During mapping in the Haystack Mountains, south-central Wyoming, which is being done primarily to determine the potential resources of coal, oil, and natural gas in the western part of the Hanna Basin, E. A. Merewether and J. R. Gill noted unusual deposits of titaniferous sandstones in the Seminoe Dam SW quadrangle. The sandstones are part of the Fox Hills Formation and contain as much as 9 percent TiO₂. Analyses of samples by S. P. Marsh showed, that the titanium is chiefly in magnetite which has been locally concentrated by placer processes.

RADIOACTIVE MATERIALS

The cumulative demand for uranium to fuel nuclear reactors for generating electricity is estimated to be 250,000 short tons of U₂O₅ by 1980 and at least 800,000 tons by 2000. As current reserves are estimated to be about 160,000 tons at a price of $8 per pound, some of the amount required by 1980 and all of that required thereafter will have to come from ore reserves and deposits not yet discovered or from lower grade materials at a substantially higher cost. Investigations by the U.S. Geological Survey are directed toward providing basic geologic information that will assist in discovery of deposits by private industry. They include mapping and other studies depicting the distribution of geologic conditions favorable for deposits, interpreting distribution and characteristics of the deposits, and leading to clearer perception of how the ore was formed.

Uranium and vanadium deposits of the Colorado Plateau and Wyoming-South Dakota regions

R. P. Fischer (r0512) summarized the geology of uranium and vanadium deposits of the Colorado Plateau region, which are the Nation's principal sources of uranium and have yielded more than $2 billion through 1964. The deposits are epigenetic in lenses of stream-laid sandstone in the Chinle and Morrison Formations, but the source of the ore metals, the nature of the ore-bearing solutions, and the times of emplacement are uncertain.

The Wyoming-South Dakota region ranks second to the Colorado Plateau region as a source of uranium, mainly from large deposits in the Wind River and Wasatch Formations (lower Tertiary). The distribution, shape, and size of these deposits were summarized by E.N. Harshman (r0613), whose geologic map of the Shirley basin, Wyoming (r1052), shows, among other features, the distribution of Wind River Formation and the configuration of the basement on which it rests.

Stratigraphic position of uranium deposits, Triassic rocks, western Texas and eastern New Mexico

According to the late J. C. Wright, uranium deposits in the Dockum Group of Late Triassic age in eastern New Mexico and the Texas panhandle occur in at least two general stratigraphic positions. The lower of these, a basal sandstone and conglomerate complex, contains many small deposits in Garza and adjacent counties in Texas. The deposits are mainly in white soft sandstone

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RESOURCES INVESTIGATIONS

containing carbonized plant debris where this rock
merges into hard, cherty sandstone containing silicified
wood. A higher uranium-bearing interval is the basal
sandstone complex of the upper part of the Dockum.
In it are many small and a few moderate-sized depos­
its in sandstone- and mudstone-matrix conglomerate in
the Canadian River valley in Texas and New Mexico
and in Briscoe and Garza Counties, Tex.

Origin of roll-type uranium deposits

H. C. Granger and C. G. Warren (r2400) proposed
that limited oxidation of early formed pyrite in the
host rock is a key factor in forming roll-type uranium
deposits. Initial products of this oxidation are a series
of unstable sulfur radicals, principally sulfite and bi­
sulfite, which slowly decompose and in so doing produce
a strong reducing environment. Iron sulfide minerals
associated with the ores resulted from recombination
of these sulfur products with ferrous iron. Sulfur iso­
topic composition of the reconstituted pyrite might be
indistinguishable from that of pyrite formed by bio­
genic processes.

Uranium precipitation from ground water, Black Hills,
S. Dak.

Uranium probably precipitates from present-day
ground water in rocks of the Inyan Kara Group of
Early Cretaceous age in the southern Black Hills,
southwestern South Dakota, according to C. G. Bowles,
who found that uranium content of water decreases
downdip. Precipitation occurs in a zone where the re­
dox potential (Eh) of the water decreases signifi­
cantly. The general position of the zone has been deter­
mined by measurements of Eh of water discharged
from artesian wells. The zone is controlled by factors
that influence the path of water flow, such as faults,
fractures, and lithologic differences, as well as by the
reducing property of the rocks.

ORGANIC FUELS

Low-sulfur coal in West Virginia

Studies of Pennsylvanian rocks in part of West Vir­
ginia, sponsored by the U.S. Bureau of Mines, indicate
that substantial reserves of low-sulfur coal are avail­
able. K. J. Englund reported coal beds in the Pocahon­
tas Formation in the southern part of the State have a
maximum sulfur content of 1 percent, and that coal
beds of the overlying New River Formation have a
sulfur content of up to 2.5 percent. D. G. Hadley re­
ported that Fayette, Kanawha, Nicholas, and Clay
Counties in the central part of the State have respec­
tively 15, 12, 8, and 5 low- to high-volatile bituminous
coal beds that include substantial reserves of low-sul­
fur coal.

Additional coal in Raton coal field, New Mexico

Areas known to be underlain by coal beds of eco­
nomic thickness in the Raton coal field in northeastern
New Mexico have been significantly enlarged. C. L.
Pillmore reported that beds of commercial thickness
are present in two localities in the western part of the
field. In one locality, two 4-foot-thick beds are present
in the middle of the Raton Formation of Late Creta­
ceous and early Paleocene age, and at the other nearby
location a 9-foot-thick coal zone containing more than
5 feet of coal in beds as thick as 3 feet is present near
the top of the formation.

Petroleum resource of Outer Continental Shelf

Estimates of crude oil, natural gas, and natural-gas
liquid reserves of the Outer Continental Shelves (of
the United States) (from limit of State jurisdiction to
2,500-m isobath) were made by S. P. Schweinfurth as a
part of the study of the mineral resources of the Na­
tion. Estimated amounts are shown in table 1 and are re­
ported for individual areas. The total petroleum of the
United States is now estimated to be 2,800 billion bbl
of crude oil, 200 billion bbl of natural-gas liquids, and
7,000 trillion cu ft of natural gas. Amounts estimated
to be recoverable under current economic conditions
and technology are 550 billion bbl of crude oil, 60 bil­
lion bbl of natural gas-liquids, and 2,700 trillion cu
ft of natural gas. These recoverable amounts include
proved reserves and cumulative production.

EXPLORATION TECHNIQUES

Analytical methods

Adaptation of atomic absorption method to geo­
chemical exploration has contributed markedly to the
precision and speed of sample analysis. At present, rou­
tine analyses are made by atomic absorption in the U.S.
Geological Survey laboratories for bismuth, cadmium,
cobalt, copper, gold, lead, nickel, silver, tellurium, and
zinc in geologic materials. A general description of at­
omic absorption methods in use is being prepared.
Other sensitive methods are being devised for molyb­
denum, gold, and silver in water and for mercury, ar­
senic, and iodine in vegetation. Experimental work is
being continued using a laser spectrograph to analyze
very small samples such as single sand-size mineral
grains, a technique which holds promise of identifying
the specific minerals that create geochemical anom­
alies.

Mineral exploration by in-situ neutron activation

Experiments were made by F. E. Sentfle, Perry Sar­
iginias, P. W. Philbin, and John Evans to improve the
TABLE 1.—Potential petroleum resources of the Outer Continental Shelf (OCS) of the United States, based on data to January 1, 1980

<table>
<thead>
<tr>
<th></th>
<th>Total potential resources</th>
<th>Recoverable resources</th>
<th>Marginal and submarginal resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude oil</td>
<td>Natural gas</td>
<td>NGL</td>
</tr>
<tr>
<td>Alaska:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCS to 200 m.</td>
<td>660</td>
<td>1,640</td>
<td>50</td>
</tr>
<tr>
<td>200-2, 500 m.</td>
<td>640</td>
<td>1,590</td>
<td>50</td>
</tr>
<tr>
<td>Pacific:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCS to 200 m.</td>
<td>30</td>
<td>75</td>
<td>2</td>
</tr>
<tr>
<td>200-2, 500 m.</td>
<td>148</td>
<td>370</td>
<td>11</td>
</tr>
<tr>
<td>Gulf:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCS to 200 m.</td>
<td>240</td>
<td>600</td>
<td>18</td>
</tr>
<tr>
<td>200-2, 500 m.</td>
<td>189</td>
<td>472</td>
<td>14</td>
</tr>
<tr>
<td>Atlantic:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCS to 200 m.</td>
<td>169</td>
<td>423</td>
<td>13</td>
</tr>
<tr>
<td>200-2, 500 m.</td>
<td>148</td>
<td>387</td>
<td>11</td>
</tr>
<tr>
<td>Totals (rounded):</td>
<td>660</td>
<td>1,640</td>
<td>50</td>
</tr>
</tbody>
</table>

in-situ neutron activation technique of mineral exploration. The most notable breakthrough has been the use of californium-252 for a source of neutrons in place of an accelerator. The small physical size of this source opens up the technique for use in borehole exploration. Most of the work has been directed toward an exploration method for gold, silver, uranium, and rare earths.

Detailed thermal and epithermal neutron mapping as a function of distance from a 14-Mev and californium-252 source of neutrons was made in several soil types. This information was used to design a detector array for exploration techniques.

Primary geochemical anomalies

Several mining districts were studied intensively for primary geochemical anomalies. In the Coeur d'Alene district, northern Idaho, G. B. Gott found that the principal mineral belts can be defined by the distribution of lead, zinc, silver, antimony, cadmium, and mercury.

In altered volcanic rocks of the northern Sierra Cuchillo, Socorro County, N. Mex., W. R. Griffits and H. V. Alminas (1980) detected anomalous amounts of lead, zinc, copper, molybdenum, and barium in an area several miles long. Thick calcite veins in this area indicate much carbonate deposition by hydrothermal solutions. This heavy-metal anomaly may be a leakage halo related to ore deposits in underlying carbonate rocks. Little exploration by drilling has been done so far in the area.

In Summit County, Colo. a study by G. J. Neuerburg and Theodore Botinelly showed that the distribution of sulfides and other accessory minerals in the Montezuma stock is related to the flow paths of hydrothermal solutions and the distribution of ore deposits in the roof zone. Distribution patterns of the zinc, cadmium, copper, manganese, and lead which can be leached from crushed quartz monzonite also indicate the mineralized areas.

Stream-sediment studies

Analysis of stream sediment continues to be an important means of evaluating the mineral potential of Primitive areas and other areas under study. Emphasis is being given increasingly to the analysis of heavy-mineral concentrates because in many areas this results in a marked enhancement of contrast between areas with anomalous and background metal contents. In their geochemical survey in Socorro County, N. Mex. W. R. Griffits and H. V. Alminas (1980) found, in the drainage system, an anomaly of possible economic significance that might have escaped notice if the only data available were metal contents of minus-80-mesh material. And in a different environment, C. L. Sainsbury and others found that some tin deposits on the Seward Peninsula in Alaska would not have been detected if the only material analysed had been the minus-80-mesh fraction of stream alluvium.

Mercury in soil gas and air

Investigations of the usefulness of the mercury content of soil gas and air as an exploration tool are continuing to show encouraging results. Mercury may be particularly effective as an exploration guide because it can indicate ore deposits covered by a thick layer of barren overburden. In Lander County, Nev., G. B. Gott and J. H. McCarthy, Jr., detected mercury which migrated from mineralized rock upwards through 1,000 feet of fractured basalt. And at Cortez,
Nev., J. H. McCarthy, Jr., R. E. Learned, and W. W. Vaughn measured anomalous concentrations of mercury in soil gas near gold-bearing deposits covered by as much as 100 feet of gravel overburden. Similar anomalies were detected in the atmosphere, using a low-flying aircraft (r079).

G. B. Gott and J. H. McCarthy, Jr., suggested that mercury vapor can be used as a prospecting guide only in the search for relatively young deposits. They found that mercury is greatly enriched (up to 200 × 10^9 ppm) in the soil gases in the vicinity of several polymetallic deposits of Tertiary age in east-central and north-central Nevada. In contrast, a relatively small amount (about 10 × 10^9 g/cu m) in the soil gases near the older (Precambrian) deposits of the Coeur d'Alene district. Also in the Coeur d'Alene district the mine gases in the unoxidized zone contain no mercury, although the sulfide vein minerals contain up to 65 ppm, thus indicating that little mercury is being released to the atmosphere from the sulfide minerals.

Biogeochemical prospecting

J. R. Keith studied the relationships of lead and zinc contents of soil and trees and their supporting soils in both background and anomalous areas in the Upper Mississippi Valley district. Soils in the mineralized areas at most sites seemed to be more reliable than plants for geochemical prospecting. Locally, however, in areas of thick loess cover, analysis of tree material proved to be a better guide than analysis of soil for detecting underlying mineralized rock.

In the Gila Mountains of Arizona, L. C. Huff showed that the mesquite tree accumulates anomalous amounts of copper, molybdenum, boron, and strontium (r1685). The molybdenum apparently is derived from molybdenum-rich ground water and locally may indicate hidden copper-molybdenum deposits.

Isotopic composition of lead as an exploration guide

The isotopic composition of lead can be a valuable guide in the search for stratiform lead-zinc deposits in the Mississippi Valley region according to R. S. Cannon and A. P. Pierce. In a worldwide survey they found that the isotopic composition of lead in stratiform lead-zinc deposits of the Mississippi-Valley type varies significantly. In the Eastern Hemisphere most deposits of this class in marine sedimentary rocks of Phanerozoic age contain ordinary lead of appropriate model age. In the Mississippi Valley region, however, comparable deposits contain so-called J-lead, relatively enriched in radiogenic Pb^206, Pb^207, and Pb^208 (r207).

For each of the four most important lead-producing districts a favorable range of lead-isotope composition can be defined which should be useful in the future search for major lead deposits. Similarly, in at least two of the districts, an area can be delineated which is most likely to contain lead of favorable composition.

In southeast Missouri, the most productive lead district in the United States, clusters of minable lead deposits in the Old Lead Belt evidently exhibit lead-isotope gradients, both vertically and horizontally, that should prove helpful in finding and developing additional mineralized ground. Among lead-isotope data so far reported from other parts of the region, Cannon and Pierce noted two localities from which particularly favorable lead-isotope analyses were published: the northern Arkansas lead-zinc district, and the barite deposits of southeast Missouri.

Borehole measurements

Borehole geophysical measurements, including resistivity, self-potential, induced polarization, gamma-ray intensity, and magnetic susceptibility logs were made by C. J. Zablocki in holes drilled under the U. S. Geological Survey's heavy metals program in north-central Nevada, northern Nevada County, Calif., and Somerset County, Maine. These data provide useful information on the in-situ properties of the rocks penetrated and have been helpful to the geologists involved in the study of the cores obtained from these drill holes.

Such measurements are proving to be a very useful aid for determining the distribution of sulfiferous gravels in Nevada County, Calif., according to H. W. Oliver and C. J. Zablocki. Of all the logs, susceptibility and temperature logs are most useful for differentiating between Tertiary gravels and volcanic breccia; self-potential logs define most of the clay-rich zones within the gravel section; and density and velocity logs show marked contrasts at the gravel-basement contact. The contacts between the volcanic rocks, gravel, and Calaveras basement are hard to identify on resistivity logs, which explains why it is difficult to define these units with surface electrical techniques.

OFFICE OF MINERALS EXPLORATION

The office of Minerals Exploration (OME) provides a program of financial assistance to private industry on a participating basis to explore for 36 eligible minerals or mineral products. Assistance is available to those who would not ordinarily undertake the pro-
posed exploration at their sole expense, and who are unable to obtain the necessary finances on reasonable terms from commercial sources. Assistance is not available to finance prospecting ventures or to develop properties for mining.

An applicant must own, lease, or have an otherwise valid right to possession of the property he wishes to explore for a term at least sufficient to complete the exploration work. A reasonable geologic probability must exist of a significant discovery of ore being made on the property. Repayment to the Government for Federal funds expended on a contract plus simple interest is at the rate of 5 percent royalty on production from the property. If there is no production, no repayment is required. The Government is not obligated to purchase any production.

The following 27 minerals or mineral products are eligible for 50 percent of the allowable costs of exploration:

- Asbestos
- Bauxite
- Beryllium
- Cadmium
- Chromite
- Cobalt
- Columbium (piezoelectric)
- Copper
- Corundum
- Diamond (industrial)
- Fluorspar
- Graphite (crucible flake)
- Iron ore
- Kyanite (strategic)
- Asbestos
- Bauxite
- Beryllium
- Cadmium
- Chromite
- Cobalt
- Columbium (piezoelectric)
- Copper
- Corundum
- Diamond (industrial)
- Fluorspar
- Graphite (crucible flake)
- Iron ore
- Kyanite (strategic)

The following 9 minerals or metals are eligible for Government financial assistance of 75 percent of the allowable costs of exploration:

- Antimony
- Bismuth
- Gold
- Mercury
- Platinum-group metals
- Antimony
- Bismuth
- Gold
- Mercury
- Platinum-group metals

Combinations of the minerals or mineral products listed in the 50- and 75-percent assistance groups may be eligible for Government financial assistance of 62.5 percent of the allowable costs of exploration.

As of March 31, 1969, 41 OME contracts were in force in 12 States, and 50 applications for financial assistance were under review.

Silver continued to lead the list as the principal commodity sought on OME contracts executed through March 31, 1969, as shown below:

<table>
<thead>
<tr>
<th>Principal commodity</th>
<th>Number of contracts</th>
<th>Total value of contracts</th>
<th>Percentage of total value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>62</td>
<td>$4,661,279</td>
<td>42.0</td>
</tr>
<tr>
<td>Gold</td>
<td>48</td>
<td>$2,557,549</td>
<td>25.1</td>
</tr>
<tr>
<td>Mercury</td>
<td>13</td>
<td>$1,026,800</td>
<td>9.3</td>
</tr>
<tr>
<td>Lead-zinc</td>
<td>7</td>
<td>$682,030</td>
<td>6.2</td>
</tr>
<tr>
<td>Copper</td>
<td>11</td>
<td>$623,350</td>
<td>5.6</td>
</tr>
<tr>
<td>Lead-zinc-copper</td>
<td>11</td>
<td>$487,641</td>
<td>4.4</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>3</td>
<td>$384,438</td>
<td>3.5</td>
</tr>
<tr>
<td>Iron</td>
<td>3</td>
<td>$199,880</td>
<td>1.8</td>
</tr>
<tr>
<td>Beryllium</td>
<td>3</td>
<td>$127,840</td>
<td>1.1</td>
</tr>
<tr>
<td>All others (cobalt, fluorspar, mica, nickel, platinum, uranium)</td>
<td>9</td>
<td>$335,970</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total (15 commodities) | 170 | $11,088,057 | 100.0 |

**MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT**

**Uncompahgre Primitive Area, Colo.**

The Uncompahgre Primitive Area is in the intensively mined, highly productive northwestern part of the San Juan Mountains in southwestern Colorado. From the 1870's to 1967, mines in the primitive area and a border zone of 1½ miles wide around it yielded about $332 million worth of metals, mostly gold, silver, copper, lead, and zinc. About 4,000 patented claims and more than 700 unpatented claims are located in or near the primitive area. Part of the ore mined by the Ida- do Mining Co. and all the ore mined at the Camp Bird mine comes from within the primitive area. In 1965, mines largely in or near the primitive area yielded nearly $83½ million in metal values, or about 32 percent of Colorado's metal production for that year. The area reserves of precious and base metals in deposits in or near the primitive area total about 8½ million tons.

In view of the mineral survey findings, R. P. Fisch er and others (r0421) concluded that insofar as mineral potential is a factor, the approximate southwestern two-thirds of the primitive area is not suitable for inclusion in the National Wilderness Preservation System.
Mission Mountains Primitive Area, Mont.

The Mission Mountains Primitive Area encompasses about 118 sq mi of the rugged Mission Range, about 40 miles north from Missoula, Mont. The area is underlain principally by slightly metamorphosed sedimentary rocks of Precambrian age (the Belt Supergroup) that have been intruded sparsely by quartz diorite of probable Tertiary age.

Geologic examination by J. E. Harrison, M. W. Reynolds, M. D. Kleinkopf, and E. C. Pattee along several hundred miles of foot traverses, plus analyses of about 500 samples, and an aeromagnetic survey did not reveal evidence of mineral deposits of potential economic significance (r0420). The study did reveal a widespread irregular distribution of minor amounts of copper and lead as primary constituents of certain kinds of sedimentary rocks, but not in sufficient amounts to form large low-grade ore deposits, nor in sufficient concentrations to form local high-grade deposits. An intensive search for strata-bound copper deposits revealed only scattered mineral occurrences.

On the basis of available data, there is little probability that mineral deposits of economic significance exist in the primitive area.

RESOURCE COMPILATIONS

Mineral resources of Arizona

Mineral resources of Arizona were summarized under the leadership of L. S. Hilpert (U.S. Geological Survey, r2579). In a report prepared jointly by the U.S. Geological Survey, the Arizona Bureau of Mines, and the U.S. Bureau of Reclamation. The report describes the geologic nature and known distribution for all the State's mineral resources, and appraises the potential for finding additional sources. Based on production data, predictable resource availability, and expected use patterns, the mineral industry of Arizona is expected to continue its rapid growth with copper maintaining its leading role. Arizona has produced over 20 million tons of copper and has led all States in copper production each year for 59 years. Recently it has accounted for more than half of all domestic production and as much as 18 percent of world production. Exploration for new deposits and development of them has been very active in recent years, and known potential resources are conservatively estimated to be about 60 million tons. Several byproduct metals are derived in processing and refining the copper ores, so that increased production of copper will also result in greater amounts of gold, silver, and molybdenum. Cumulative production of these metals is nearly 14 million oz of gold, 400 million oz of silver and 60 million lb of molybdenum. Over a million tons of zinc and about 650,000 tons of lead have been produced from more than 250 mines in some 118 mining districts. Many of these mines were also producers of associated gold and silver. Nearly 3 million tons of uranium ore containing over 8,000 tons of uranium oxide have been produced in Arizona from several hundred deposits. Potential iron-ore resources have been developed to only a limited extent. Additional resources of these and other metals are currently the target for intensive exploration.

A significant development in Arizona's mineral industry is the recent large expansion of coal mining in the Black Mesa coal field to supply fuel for a thermal powerplant. A long-term contract for delivery of at least 117 million tons of coal over a 35-year period provides a major economic impetus to a sector of the mineral industry that has long been limited because of remoteness from major markets. Oil and gas exploration and development in the State have been stimulated by the discovery of the Dineh-bi-Keyah oil field, the first well of which was completed in February, 1967. Subsequent development has brought production of crude oil in the State to over 2 million bbl annually.

Abundant resources of nonmetallic minerals and construction materials have become increasingly important with growth in population and industries, and with better access to these new markets. The annual sand and gravel production is second in value to copper, with significant additional production in stone, clays, pumice, gypsum, and asbestos.

Mineral resources of Oregon

Mineral resources of Oregon were summarized under the leadership of A. E. Weissenborn (U.S. Geological Survey, r2580) in a report prepared jointly by the U.S. Geological Survey, the Oregon Department of Geology and Mineral Industries, the U.S. Bureau of Reclamation, the Bonneville Power Administration, and the U.S. Bureau of Mines. The report describes the character and distribution of known and potential mineral resources, and provides data on production and use, and an estimate of potential developments for each commodity. Much of the present vigor of Oregon's mineral industry is related to expanded markets for such construction materials as sand and gravel, stone, clay, and gypsum. These and other nonmetallic commodities account for over 75 percent of the value of mineral raw materials in recent years.

Early mining in Oregon centered on the search for precious metals. Beginning with the discovery of gold in 1850, gold production now totals about 5.8 million oz, and silver production is just slightly less. Much of this production came in the first 25 years, and provid-
ed much of the capital for the pioneer economy of the State. The known resources of gold and silver are low grade and mostly associated with deposits of copper, lead, and zinc. Most of these deposits were initially discovered in the early search for high-grade precious metal lodes, and were not economic at that time. The report recommends that modern exploration techniques should be applied in a number of areas containing these deposits. Nickel mining, which did not begin until 1954, has provided an even greater value than gold; Oregon’s nickel mine provides only the domestic production. Potential resources of nickel are adequate to maintain the current production rate for several years, and lower grade nickeliferous laterites may ultimately be developed. Other metallic resources that have been exploited include mercury, chromite, and uranium. Mercury has been reported in some 225 deposits, of which more than 60 have been productive. Of the 105,000 flasks of mercury produced in the state, 90 percent has come from 5 mines. Known chromite resources are too low grade to support production except during times of very high prices. The recorded production of 147,000 long tons represents three such periods of wartime price stimulus. Uranium production also reflects the effect of exploration prompted by high prices. The known deposits produced 200 tons of uranium oxide from 120,000 tons of ore. The promising market outlook for uranium should encourage exploration for additional deposits.

Coal resources of Oregon are capable of supporting moderate-sized mining activities, but have been mined mainly for local needs. Exploration for oil and gas has been unsuccessful so far, but many areas have not been fully tested. Present interest in offshore exploration is quite high. The report summarizes much stratigraphic and structural data as a guide for further drilling.

Mineral resources of Wisconsin

Maps of the Precambrian of the northern half of Wisconsin were prepared under the joint auspices of the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey. Geologic data are shown at a scale of 1:500,000, compiled by C. E. Dutton and R. A. Bradley from mineral-land classification surveys conducted from 1913 to 1930. Four sheets were released in open files, showing: (1) information on felsic rocks according to lithologic type; (2) delineation of greenstones and foliated mafic rocks; (3) geologic map of sedimentary rocks; and (4) magnetic contours based on aeromagnetic surveys, and crest and trough lines of magnetic anomalies determined from dip-needle surveys. The maps will be further explained in a report now being prepared for publication.
K. G. Bell. The major faults are northeast-trending strike-slip faults having displacements of many miles; myriads of lesser faults are interspersed between the major faults. Magnetic and gravity surveys of the Gulf of Maine indicate that some of the major faults extend seaward as far as Georges Bank, and the fault zone extends northeastward to the Maritime Provinces of Canada. Differences of rock types across one of these faults mapped by A. F. Shride in the Newburyport West quadrangle, Massachusetts (locality 1, index map), indicate considerable lateral displacement. Other faults in this system mapped in the Natick quadrangle, Massachusetts (loc. 2), by A. E. Nelson appear to have right-lateral displacement (of at least 6 miles along one fault), and to merge with the border fault of the Boston basin. A northwest-trending fault of considerable displacement was identified in the Medfield quadrangle, Massachusetts (loc. 3), from field mapping and ground radioactivity survey by R. P. Volckmann. A columnar section of metasedimentary rocks in northeastern Massachusetts that is being compiled by N. P. Cuppels and Bell is expected to help unravel the structural complexities.

![Map of New England States](image)

The Lake Char trust fault of northeastern Connecticut was traced by H. R. Dixon across the Thompson quadrangle, Connecticut (loc. 4), to the Massachusetts boundary. In the center of the quadrangle the fault splits into three or four imbricate thrust slices in which mylonitized quartzite from the lower plate and hornblende gneiss from the upper plate are intermixed. At an adjacent S-bend the fault apparently cuts across units in the lower plate at a high angle; this is the only place where such truncation along the fault can be demonstrated.

**Side-looking radar shows structures**

Mosaics of side-looking radar imagery of Massachusetts provided by the Grumman Aircraft Engineering Corp. were analysed by M. H. Pease, Jr. In areas where the geology is well known, patterns of bedding and foliation could be distinguished from lineaments (presumably faults) that trend subparallel to or crosscut stratigraphic trends. In areas of less well known geology, the most conspicuous lineaments also trend generally northeast. These lineaments commonly separate distinctive patterns on the mosaics into structural blocks. Side-looking radar imagery should be useful for the interpretation of the regional geology.

**Structural studies in southwestern Massachusetts**

Recent mapping in the State Line quadrangle (loc. 5), by N. M. Ratcliffe revealed clear evidence for the allochthony of the Chatham slice of the Taconic allochthon. Rensselear Graywacke and rocks of the Nassau Formation of probable Early Cambrian age rest discordantly on the Stockbridge Formation of Cambrian and Ordovician age. Moreover, map units within the Nassau Formation are discordant with the sole of the thrust.

Studies by Ratcliffe in the Stockbridge, Great Barrington, and Ashley Falls quadrangles (loc. 6), show large-scale westward movement of Precambrian basement rocks in low-angle thrusts. Thrust slices of Cheshire Quartzite and Dalton Formation (Lower Cambrian), overlain locally by Precambrian rocks, crop out in an irregular belt to the west of these thrusts. The autochthonous Stockbridge and Walloomsac Formations of Cambrian and Ordovician age beneath the thrusts form broadly recumbent folds that are strongly refolded. Because the structural pattern within the overthrusts coincides only with the latest set of structures in the autochthon, it is thought that the thrusting was a relatively late structural event.

Precambrian gneisses in the South Sandisfield quadrangle (loc. 7), mapped by D. S. Harwood, were folded into a large recumbent antiform with axial surface dipping gently east, and refolded into domes and basins about north-trending, steeply dipping axial surfaces.

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Subdivision of Brimfield Schist

Work on the stratigraphy and structure of the schists and gneisses of the Brimfield Schist continues in several parts of northeastern Connecticut and south-central Massachusetts. Eleven major map units defined in the Westford quadrangle, Connecticut (loc. 8), by J. D. Peper form a west-dipping homoclinal sequence broken by thrust faults and complicated by small folds. Field evidence indicates that regionally west-over-east shearing continued later than the peak of sillimanite-orthoclase-grade metamorphism into the time of emplacement of late pegmatites. In the Monson quadrangle, Massachusetts (loc. 9), gray schist and gneiss overlie sulfidic sillimanite schist and gneiss; graded bedding indicates that the gray unit occupies the axial parts of two isoclinal synclines.

A homogeneous sequence of rusty sillimanite schist and felsic gneiss was traced by M. H. Pease, Jr., from the Stafford Springs quadrangle into the type area of the Brimfield Schist in the Wales quadrangle, Massachusetts (loc. 10). This belt widens to the northeast, but appears to be progressively cut out to the southwest by a major north-south structure; bedding dips consistently northwest. Layers of similar rusty schist are common in other stratigraphic units below the base of the type Brimfield.

In the Southbridge quadrangle, Massachusetts (loc. 11), G. E. Moore, Jr., identified mappable calc-silicate and volcanic units within the Brimfield Schist.

Stratigraphic sequences in western Massachusetts and adjacent Connecticut

The sequence of Paleozoic stratigraphic units of the east limb of the Berkshire anticlinorium traced southward by N. L. Hatch, Jr., from Vermont to Blandford, Mass. (loc. 12), is significantly different from the sequence of units being mapped in northern Connecticut by R. W. Schnabel. Possible explanations for the change include considerable transport along a fault mapped in the West Granville quadrangle, Massachusetts (loc. 13), by Schnabel, and a major facies change in the vicinity of Blandford inferred by Hatch and R. S. Stanley.

Triassic wind action

Wind-polished pebbles are abundant in a bed of Triassic conglomerate near Glastonbury, Conn. (loc. 14), according to J. P. Schafer. This is the first direct evidence of wind action during deposition of the Triassic rocks of the Connecticut Valley.

Stratigraphic revision in northwestern Maine

Stratigraphic and structural evidence found by D. S. Harwood (p. D106-D115) in the western part of the Arnold Pond quadrangle, Maine (loc. 15) indicates that at least part of the belt of volcanic rocks, greywacke, and slate originally assigned to the Frontenac Formation and Kidderville Formation of Hatch12 of Devonian age underlies rocks of probable Silurian age, and is probably equivalent to part of the Dixville Formation of Middle Ordovician age. If so, this belt outlines a narrow northeast-trending anticline on the northwest limb of the Boundary Mountain anticlinorium.

STUDIES OF IGNEOUS ROCKS

Attean pluton, northwestern Maine

The Attean pluton in the Chain Lakes and Kennebecago Lake quadrangles (loc. 16) was subdivided by E. L. Boudette into (1) a layered ultramafic massif composed principally of serpentinite, pyroxenite, and epidiorite, and (2) the relatively younger Attean Quartz Monzonite. The presence of abundant epidiorite in the massif suggests that it is of the alpine type. Both intrusive units are apparently intruded conformably at the boundary between a schist-gneiss-granofels complex on the northwest and a metamorphosed eugeosynclinal sequence in the lower greenschist facies on the southeast.

Mafic rocks, eastern Massachusetts

Almost all dark gabbros and diorites in eastern Massachusetts were previously assigned to the Salem Gabbro-Diorite. According to K. G. Bell, these rocks belong to at least three magma series: (1) nonfoliated gabbro and diorite plutons of Late Devonian age or younger; (2) foliated garnet-bearing diorites and quartz-diorites of the New Hampshire Plutonic Series of Devonian age; and (3) chloritized and epidotized gabbros and diorites of Early Devonian age, or older.

Volcanic rocks near Medfield, Mass.

A welded tuff containing devitrified glass shards and rock fragments in an aphanitic matrix was mapped1 in the Medfield quadrangle (loc. 3) by R. P. Volckaart. The tuff may occupy a vent area possibly related to nearby porphyritic intrusives of similar composition.

MINERALOGICAL AND ISOTOPIC STUDIES

Metamorphic assemblages in northwestern Maine

Regional equilibrium assemblages in rocks in the Kennebecago Lake quadrangle (loc. 16) mapped by E. L. Boudette are: (1) chlorite-epidote-caliche-actinolite-zeisite, (2) quartz-plagioclase-epidote-chlorite, and (3) quartz-chlorite-epidote-muscovite(!). These assemblages are either prograded from clastic sediments and

retrograded from hypobyssal intrusives, or entirely altered from previous (Taconic) equilibrium assemblages. An injection gneiss in the amphibole hornfels facies at the southwestern end of the Stratton pluton shows this reaction assemblage: plagioclase-amphibole-quartz-biotite-cordierite-sillimanite-garnet (with or without tourmaline-sphene-epidote). This assemblage is probably not in equilibrium.

Metamorphic chronology in western New England

Electron-probe analysis of selected plagioclase porphyroblasts from the metamorphic rocks of southwestern Massachusetts shows, according to E-an Zen, that the feldspar was extensively retrogressively metamorphosed; the crystals are now rimmed by nearly pure albite and the intermediate, most Ca-rich zones are commonly saussuritized. Mica in such altered zones is oriented parallel to rock foliation. The relations indicate that the Acadian radiometric age dates a late event, and that the peak of metamorphism, at least for some of the rocks, occurred earlier. Combined with indications of pre-Silurian metamorphic event elsewhere in New England and adjacent New York and Quebec, based both on radiometric dating and on petrographic data, the information leads to the inference of a widespread regional metamorphic event about 400-450 m.y. ago affecting an area extending at least from southeastern Quebec to southeastern New York.

Ages of alkaline plutons, eastern Massachusetts

A geochronologic study by R. E. Zartman and R. F. Marvin of several alkaline plutons in eastern Massachusetts yielded the following radiometric ages:

<table>
<thead>
<tr>
<th>Rock unit</th>
<th>Rb-Sr whole-rock isochron (m.y.)</th>
<th>K-Ar hornblende (m.y.)</th>
<th>Pb²⁰⁷-Pb²⁰⁶ zircon (m.y.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peabody Granite</td>
<td>367 ± 12</td>
<td>359, 362, 371</td>
<td>435 ± 12</td>
</tr>
<tr>
<td>Cape Ann Granite</td>
<td>433 ± 6</td>
<td>375, 402</td>
<td>380 ± 16</td>
</tr>
<tr>
<td>Quincy Granite</td>
<td>data scattered</td>
<td>430, 437, 444, 447, 457</td>
<td>450 ± 55</td>
</tr>
</tbody>
</table>

All the granites give some evidence of an Ordovician age, and this is considered as the most likely time of emplacement for all the alkaline plutons. The Cape Ann Granite gave a well-defined Rb-Sr whole-rock and Pb²⁰⁷-Pb²⁰⁶ zircon age which is Late Ordovician on the presently accepted time scale. The closely agreeing K-Ar hornblende and Pb²⁰⁷-Pb²⁰⁶ zircon age of the Quincy Granite appears to reflect a Late Ordovician time of emplacement similar to the Cape Ann Granite. The older of the two Pb²⁰⁷-Pb²⁰⁶ zircon ages of the Peabody Granite is probably more reliable. Gabbroic to granitic rocks that are older than the alkaline plutons but post-†Olenellus apparently were intruded in Cambrian or Ordovician time. A concordant Rb-Sr and K-Ar phlogopite age of about 490 m.y. for the gabbro at Nahant supports this conclusion. The low metamorphic grade of pre-Devonian sedimentary rocks, the contrasting tectonic styles, and the likelihood of a major intervening fault system distinguish this area from adjacent central Massachusetts and New Hampshire where many of the igneous rocks date from the Early to Middle Devonian Acadian orogeny.

Metallic mineral deposits

Iron formation in northeastern Maine

Manganiferous iron formation of both the hematitic and carbonate types occurs in lenses within the Smyrna Mills Formation of southern Aroostook County, according to Louis Pavlides. Locally a stratigraphic zone with iron- and manganese-bearing lenticular deposits strikes into the biotite-cordierite hornfels aureoles of two granitic plutons. Within these contact-metamorphosed zones the manganese- and iron-bearing deposits have been metamorphosed chiefly into magnetite-comingtonite-garnet ironstones which also may locally contain fayalite and pyroxmangite. Preliminary microprobe analysis indicated that the manganese is mostly in the garnet but is also contained in the cummingtonite. Some of the large magnetic anomalies associated with the hornfels aureoles are caused by such lenticular magnetite-bearing ironstones.

Deposits in northwestern Maine

One of the small plutons of quartz porphyry mapped by E. L. Boudette in the Chain Lakes quadrangle (loc. 16), north of Big Jim Pond, appears to be a breccia pipe, and bears macroscopic amounts of base metal sulfides. Amphibolites associated with serpentinite in the Arnold Pond quadrangle, sampled by D. S. Harwood, contain 0.2–0.5 percent Ni, 0.7–3.0 percent Cr, and as much as 0.5 ppm Au.

Gold-bearing erratic in central Massachusetts

A gold-bearing boulder found in drumlin till in Stow, in the Hudson quadrangle, by J. H. Peck, is made up chiefly of quartz, arsenopyrite, and iron oxide (limonite?) with minor pyrite and chalcopyrite. Analysis of a chip sample showed a gold content of 30 ppm (about $30 per ton). The internal structure of the boulder strongly suggests that the rock was derived from fault gouge or breccia, but its original source is unknown.

Sulfides in north-central Connecticut and adjacent Massachusetts

Pyrite, chalcopyrite, and barite were found by M. H. Pease, Jr., in boulders of silicified breccia of Triassic
sedimentary rock in two pits in glacial till, one in the Ellington quadrangle, Connecticut (loc. 17), and the other in the Hampden quadrangle, Massachusetts-Connecticut (loc. 18). As both pits are near the east border fault of the Connecticut Valley Triassic basin, there is a strong possibility that a sulfide deposit is buried beneath glacial cover along the fault.

Pyrite and pyrrhotite are common constituents of the Brimfield Schist widely exposed in much of the Stafford Springs (loc. 19) and adjacent quadrangles in Connecticut. The sulfides, disseminated along bedding planes and joints, evidently were originally of sedimentary origin. No associated copper, zinc, or lead sulfides have yet been found in these rocks.

SEISMIC PROPERTIES OF FRACTURED ROCK AND SAPROLITE

In highly fractured rocks, refraction seismic compressional wave speeds are abnormally low. Thus a fractured intermediate layer found during a seismic survey for civil-engineering foundation purposes commonly will be reported as soil, because of the low velocity, whereas actually the fractured rock commonly requires systematic drilling and blasting for removal. An experiment to relate field compressional speed to the frequency and width of visible cracks has been started by C. R. Tuttle. Measurements have been made at sites in granites and gneisses in Massachusetts. Within the outcrop areas studied the total crack area ranged from 0.2 to 1.5 percent. Low apparent velocities are associated with abundance of cracks 6 mm or less wide. Higher apparent velocities occur with cracks 10 to 20 mm wide, but of lower frequency.

At a highway location in Shrewsbury, Mass. (loc. 20), saprolite and fault gouge were associated with a recognizable, characteristic shape of the refraction seismic traveltine curves obtained by C. R. Tuttle. Prior to excavation this material was interpreted as "unidentified material" with an average apparent velocity of 4,000 fps. At a recent seismic study site in Oxford, Mass. (loc. 21), traveltine curves again have the character of those at Shrewsbury. If fault gouge or saprolite is revealed by excavation at the Oxford locality, this will confirm the use of traveltine curves in identification of such material.

PLEISTOCENE GEOLOGY

Two tills in northern Connecticut

The glacial deposits in a gas line trench 16 miles long and 8-15 feet deep in northeastern Connecticut were studied by M. H. Pease, Jr. Most upland areas were blanketed by two superposed tills. The upper till is olive gray, friable, sandy, commonly contains lenses of sand or gravel, and has a greater proportion of sub-rounded stones; the lower till is olive brown, compact, and has platy jointing. These same two tills have been recognized elsewhere in southern New England, and commonly believed to be the deposits of two ice advances. However, evidence from the trench favors their deposition as ablation and lodgement tills of a single ice advance.

A section of upper till 30 feet thick in the Torrington quadrangle, (loc. 22), northwestern Connecticut, was interpreted to contain both ablation and lodgment zones from texture, bedding, and stone fabric studies by Fred Pessl, Jr. Measurement of shape and roundness of 250 stones indicated that, at this locality, shape is a more sensitive indicator of the environment of till deposition than is roundness. Stones from that part of the exposure interpreted to be of lodgement origin have a mean sphericity of 0.67-0.68 and a mean roundness of 0.35-0.38; 20-21 percent of these stones are spheroids (in the Zingg classification). Stones from that part of the exposure inferred to be of ablation origin have a mean sphericity of 0.70-0.72 and a mean roundness of 0.38; 38-40 percent of these stones are spheroids.

Modification of drumlins, Connecticut Valley

Some drumlins with north-south long axes in the Hampden quadrangle (loc. 18), Massachusetts-Connecticut, apparently were modified during the waning of glaciation in the Connecticut Valley, according to R. B. Cotton. The ice front was lobate, drumlins then under the edge of the ice were reshaped either through erosion or addition of till, and "parasitic" drumlins whose long axes are oriented northwest-southeast resulted. This hypothesis may explain the origin of southwest-trending "tails" on several drumlins in previously mapped quadrangles to the south and southwest.

Last glaciation in central Massachusetts

The last ice sheet advanced due south in the Mount Tom quadrangle (loc. 23) as indicated by striations and streamlined topography mapped by F. D. Larsen. Erratics of the Belchertown Tonalite were carried southward at least 16 miles. Retreat of the ice margin west of the Holyoke Basalt ridge was interrupted by three stillstands or slight readvances of the ice margin, each of which is marked by a head of outwash composed of coarser material. Thrust faults and folds in varved clay and sand overlain by till indicate a minor readvance in the southwest portion of the quadrangle.

Drainage diversions in northwestern Connecticut

C. R. Warren (p. D200-D205) found that glacial deposition disrupted parts of the preglacial drainage
system in the Norfolk quadrangle. (loc. 24). Of four preglacial streams in the headwaters of the Blackberry River, three were diverted across former divides. Much of the glacial drift that caused the disruption was deposited in a temporary glacial lake in the Blackberry River basin.

Late-glacial wind action in southern New Hampshire

Two wind-polished bedrock localities in the Manchester quadrangle, (loc. 25), the first reported from New Hampshire, indicate a late-glacial wind from N. 65° W, according to Carl Koteff. This is in some contrast to directions at localities in Massachusetts, which indicate predominant late-glacial winds from north and northeast. Sand dunes as much as as 30 feet thick on the east side of the Merrimack River valley may be related in time to the wind polishing.

Glacial lakes in the Housatonic Valley

Additional evidence that a glacial lake left abundant clay deposits in the Housatonic Valley results from studies in the Ashley Falls quadrangle, (loc. 6), Massachusetts and Connecticut, by G. W. Holmes and W. S. Newman. The retreating ice sheet left the Housatonic Valley early, while bodies of dead ice still lay in tributary valleys such as that of the Konkapot River. However, mapping in the Kent and Ellsworth quadrangles (loc. 26) to the south in Connecticut by G. C. Kelley revealed no evidence that such a lake extended that far south. In the Housatonic Valley lacustrine deposits are lacking and ice-contact deposits are widely distributed.

APPALACHIAN HIGHLANDS AND THE COASTAL PLAINS

APPALACHIAN PLATEAUS AND VALLEY AND RIDGE PROVINCES

Stratigraphic and paleoenvironmental studies of Paleozoic rocks

In a study of Lower Pennsylvanian and Upper Mississippian rocks in southwestern Virginia and southern West Virginia, K. J. Englund noted an unconformity in the lower part of the New River Formation that truncates older beds toward the northwest, including the Pocahontas Formation and the upper part of the Bluestone Formation. The unconformity marks a hiatus between the Mississippian and Pennsylvanian Systems where the eroded beds are absent. This relation suggests that the widely recognized Mississippian-Pennsylvanian unconformity lies within Lower Pennsylvanian rocks in the study area.

Wallace de Witt, Jr. found that in the southern part of the Hyndman quadrangle, Pennsylvania, (locality I, index map) the Keefer Sandstone of Silurian age is not a simple sheet sandstone, but consists of a series of lenses of well-sorted, fine- to medium-grained quartzite as much as 25 feet thick and a mile long. These lenses are intercalated in a 6- to 20 foot-thick sequence of thin-bedded, fine-grained sandstone, siltstone, and silty fossiliferous mudrock. Locally, sandy fossiliferous hematite is associated with the Keefer Sandstone. Several exposures show two zones of thin-bedded sandstone separated by as much as 10 feet of silty mudrock. The Keefer appears to have accumulated as a series of small offshore bars and related marine sheet sands spread during regression of the Silurian sea in which the underlying Rose Hill Formation was deposited. The Keefer Sandstone bodies appear to be time transgressive from east to west.
and lagoonal environments, whereas the Bloomsburg Red Beds at the top of the sequence were deposited by meandering streams on a low alluvial plain. These deposits all represent detritus shed northwestern from highlands uplifted during the Taconic orogeny.

During the same study J. B. Epstein and A. G. Epstein found phosphate, siderite, and chloride (chamosite?) nodules in the Clinton Formation for the first time in eastern Pennsylvania. The nodules are probably primary or early diagenetic, and, along with occurrences of Lingula, indicate deposition in a shallow subtidal, lagoonal, or tidal flat environment.

The Epsteins also reported the discovery of montmorillonite in carbonate rocks of late Silurian age in eastern Pennsylvania. These rocks are believed to have been deposited in an intertidal, and supratidal environment. Comparison with Middle Silurian clastic rocks that lack montmorillonite and were probably deposited in the same environment suggest that the montmorillonite is an early diagenetic or penecontemporaneous authigenic mineral. The reflux mechanism suggested for dolomitization of carbonates in recent sediments in many parts of the world may be responsible for the origin of the montmorillonite.

Isopach maps in Ohio and Kentucky established the existence of a large pre-Middle Ordovician anticline in the subsurface called the Waverly arch. The crest of the arch plunges southward from Ohio into east-central Kentucky, where it terminates abruptly against a major east-west basement fault. An isopach map constructed by L. D. Harris from sparse drilling data, thickness measurements from outcrop sections, and published reports in Tennessee and southwest Virginia suggests that structure south of the central Kentucky fault is dominated by a large anticline, whose crest lies in the subsurface of West Virginia many miles east of the crest of the Waverly arch. During the time that the arch was a positive feature carbonates of the Knox Group, the uppermost rocks involved in the structure, were subjected to intense weathering. The possibility exists that the porosity thus produced may have been great enough to have formed a major trap in the subsurface of West Virginia for future oil and gas exploration.

Structure of the Valley and Ridge belt

Study of the Round Mountain area (loc. 3) in Etowah and Cherokee Counties, Ala., by R. A. Laurence, indicates that the large, roughly circular area of Floyd Shale (Mississippian) which is surrounded by

The age and mode of formation of the cleavage in the Martinsburg Formation in eastern Pennsylvania
has been in debate since Maxwell suggested that it formed diagenetically in water-bearing pelites owing to high pore pressures. J. B. Epstein identified the 2M polymorph of muscovite in five samples of slate from different parts of the formation. This is contrary to Maxwell's identification of the mica in the slate as a lower ordered form ("illite"). The presence of 2M muscovite strongly suggests but does not prove that the slate is a metamorphic rock inasmuch as the stability ranges of the polymorphs of muscovite are not accurately established and the muscovite, may reflect the nature of the source rocks. However, occurrence of chlorite porphyroblasts and elongate quartz is a strong argument for metamorphism and not diagenesis. Epstein also showed that arching and dying out of cleavage in the Martinsburg Formation near the unconformable contact with the overlying Shawangunk Conglomerate of Silurian age in Blue and Kittatinny Mountains in eastern Pennsylvania and northeastern New Jersey (loc. 2) probably is due to a large scale pressure-shadow mechanism. Similar features have been observed on smaller scale in outcrop. This proves that the conspicuous cleavage in the Martinsburg is post-Silurian in age and not a product of the Taconic orogeny.

Clastic and some carbonate rocks near Clinton and Jutland, N.J. (loc. 6), contain graptolites of both Early and Middle (Deepkill) and Middle (Normanskill) Ordovician age but have been referred to the Martinsburg Shale of Trenton and younger age. Reconnaissance by A. A. Drake, Jr., showed that these rocks are very similar to allochthonous rocks of the Hamburg klippe of eastern Pennsylvania, as well as to rocks in the Peapack Valley of New Jersey, which contain brachiopods of Middle Ordovician age. Only tectonic (?) slivers of Jacksonburg Limestone underlie these clastic rocks which are in fault contact with carbonate rocks of Cambrian and Early Ordovician age as well as with Precambrian crystalline rocks. It would seem that a sequence of rock ranging from at least Early to Middle Ordovician age is allochthonous. Because no rocks whose assignment to the Martinsburg can be confirmed, emplacement by gravity sliding during geosynclinal deposition is unlikely. The rocks probably were emplaced in thrust sheets from a southeastern source after the emplacement of the Taconic nappes in the nearby Reading prong. This implies an eastern basin of deposition in the central Appalachians like that in the northern Appalachians.

**Tectonics of the Reading prong**

Continuing analysis of geological and geophysical data from the Reading prong and Great Valley of eastern Pennsylvania and New Jersey (loc. 6) by A. A. Drake, Jr., suggests that another regional nappe may be largely buried beneath the recently defined Musconetcong nappe. The probable core of this buried structure is defined by a large subsurface aeromagnetic anomaly centered near Catasaqua, Pa. This anomaly can be traced northeastward transverse to the grain of the outcropping rocks, from Lyon Station, Pa., where it emerges from beneath the outcropping Precambrian rocks of the Musconetcong nappe to the northeast limit of the aeromagnetic survey near Bangor, Pa., a distance of about 40 miles. The magnetic rocks causing this anomaly are about 1 mile below the surface. The anomaly cannot be a basement phenomenon because the basement here is deeper than 25,000 feet. Directly on strike with the anomaly in New Jersey is the carbonate-floor Paulins Kill valley which is surrounded by the Martinsburg Formation. The structure of the carbonate rocks in the valley is anticlinal, but they are bounded on all sides by the same fault as shown by A. A. Drake, J. B. Epstein, and J. M. Aaron (1965). The Jacksonburg Limestone exposed in the valley is of a different facies than at any place within the Great Valley or Reading prong, and the lower part is distinctly older than any other Jacksonburg. The carbonate rocks appear to be largely right side up, and therefore were interpreted as being the upright limb of a nappe. The presence of a lower limb cannot as yet be demonstrated. The structure can be traced for at least 70 miles.

**THE BLUE RIDGE AND PIEDMONT**

**Age determinations on Precambrian volcanic rocks of the Blue Ridge**

In a joint study by T. W. Stern, M. F. Newell, D. W. Rankin, and J. C. Reed, Jr., zircon ages were determined on five felsic volcanic rocks in the widely separated upper Precambrian stratigraphic units of the Blue Ridge. The uranium-lead ages are discordant and, using the episodic-lead-loss model, define a chord in the Pb$^{207}/U^{235}$-Pb$^{206}/U^{238}$ concordia diagram indicating an original age of about 820 m.y. and a lead-loss age of about 240 m.y. Units dated are the

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Mountain Formation in North Carolina, the Mount Rogers Formation in Virginia, and the Catoctin Formation at South Mountain, Pa.

These units all rest unconformably on billion-year-old granite rocks; the latter two are overlain with apparent conformity by Lower Cambrian (?) rocks of the Chilhowee Group. The zircon ages suggest that all the felsic volcanic rocks are virtually the same age and are Precambrian rather than Cambrian as suggested by some workers. The dates indicate that there is a major hiatus at the base of the of the Chilhowee Group.

Previously published zircon ages on basement rocks from Tennessee and western North Carolina define two additional chords both of which intersect the concordia curve near 240 m.y. The convergence of three independently determined chords suggests that a geologic event disturbed the zircons about 240 m.y. ago. Lead loss is not related to regional metamorphism and granitic plutonism which mineral ages date as about 350 m.y. age in the southern Blue Ridge. The lead loss may have occurred during movement of the Blue Ridge thrust sheet in the Late Paleozoic at the same time as thrusting in the western Valley and Ridge belt. A single age of thrusting is consistent with thin-skinned tectonics.

Precambrian glacial deposits recognized

Red matrix conglomerate (tillite) and associated laminated pebbly mudstone (varved sediments) at the top of the Mount Rogers Formation (upper Precambrian) in southwestern Virginia are attributed to alpine glaciation by D. W. Rankin. Laminated pebbly mudstone occurs sparsely in the highest exposed part of the Grandfather Mountain Formation in western North Carolina and may also be of glacial origin. If so, the area of Precambrian glaciation appears to have been at least as large as 350 sq mi. In both areas the glacial deposits are above felsic volcanic rocks included in formations having discordant zircon ages that indicate an original age of 820 m.y. Many Precambrian rocks attributed to glaciation elsewhere in the world are also red.

Epidotization and spilitization in greenstone

The Catoctin Formation in the Blue Ridge of central Virginia consists principally of greenstone of spilitic composition and pods and irregular masses of quartz-epidote rock (epidosite). Relict original textures and structures show that these rocks were derived from redistribution of components within subaerially extruded basalt flows. Detailed studies of the chemistry and mineralogy of these rocks by B. A. Morgan, III and J. C. Reed, Jr., and estimates of relative proportions of greenstone and epidosite based on photographs of selected outcrops suggest that these rocks are products of differentiation during low-grade regional metamorphism without introduction of material. The bulk composition of the greenstone-epidosite sequence closely approximates that of metabasalt feeder dikes that show no signs of epidotization or spilitization. Field relations and thermodynamic considerations suggest that the epidotization was controlled by local oxidation of the original basalt along joints and flow boundaries by deuteric solutions or hot meteoric waters prior to metamorphism.

Age and correlation of the Glenarm Series

The age and stratigraphic relations of the Glenarm Series in the Maryland and Pennsylvania Piedmont have been subjects of controversy for at least 50 years. Several recent workers including Hopson and Wetherill and others concluded that the Glenarm Series is probably of Precambrian age. However, new evidence is accumulating that part or all of the Glenarm may be of Paleozoic age.

M. W. Higgins found that the Port Deposit Gneiss and several other granitic rocks in the Maryland Piedmont (loc. 7) are probably of sedimentary origin like the Sykesville Formation of previous usage. These "granitic" rocks all yield zircon ages in the range 500 to 550 m.y. Inasmuch as the rocks were interpreted as intrusive into the Glenarm Series these ages were assumed to represent a minimum age for the Glenarm. If the granitic rocks are of sedimentary origin, the zircons are detrital and their age represents a maximum, not a minimum, age for the Glenarm.

In mapping the New Windsor quadrangle (loc. 8) in the western Piedmont in Maryland, G. W. Fisher found two lithologic associations: (1) metabasalt interbedded with clean dolomitic marble locally containing stromatolites and oolites, probably deposited in shallow water; and (2) muscovite-chlorite phyllite interbedded with argillaceous limestone, thinly laminated and locally graded, probably deposited in deeper water. These rocks are probably contemporaneous with the Cambrian and Ordovician limestones of the folded Appalachians and may mark the eastern edge of the miogeosynclinal shelf. If so, they probably represent a facies transitional into the deeper water rocks of the Glenarm Series.

Detailed mapping by D. L. Southwick in the Quantico quadrangle, Virginia (loc. 9), showed that the Quantico Slate, from which Ordovician fossils were reported long ago, is underlain by several thousand feet of felsic and mafic volcanic and volcanioclastic rocks. These in turn are underlain by a thick mass of pebbly granitic-appearing gneiss much like part of the Wissahickon Formation of the Glenarm Series. In reconnaissance, R. B. Mixon and J. C. Reed, Jr., traced the Quantico Slate and the underlying volcanic rocks southwestward to the Rappahannock River. This indicates that the underlying Wissahickon is very probably correlated with the Evington Group (Paleozoic(?)) of the western Virginia Piedmont rather than with the Lynchburg Gneiss (Precambrian).

Geophysical studies of the Baltimore gabbro

A detailed gravity survey by J. W. Allingham indicates that the Baltimore gabbro complex in Howard County, Md. (loc. 10), is a folded overturned, podlike body. Aeromagnetic data and magnetic measurements of samples confirm that the altered mafic and ultramafic rocks at the western border of the complex have reversed polarity, whereas the main body of gabbro has normal polarity. The border rocks of the complex are serpentinite and amphibole-chlorite schist that produce narrow magnetic lows. The main body consists of massive metagabbro that has a rather flat aeromagnetic expression. The relatively unaltered hypersthene gabbro is associated with magnetic highs. The complex pattern of discontinuous aeromagnetic lows irregularly distributed over the gabbro indicates a similarly complex pattern of interlayered ultramafic and mafic rocks, which is also characteristic of alpine-type complexes.

Geologic and geophysical studies in the Carolina slate belt

Lynn Glover III and O. T. Tobisch (p. C1-C7) found a regular increase in metamorphic grade northward across the boundary between the Charlotte and Carolina slate belts at the Virginia-North Carolina slate line (loc. 11). Regional metamorphic facies range from greenschist in the slate belt to upper amphibolite in the Charlotte belt. Field and laboratory evidence suggests that a metamorphic gradient is one of the principal factors that defines the boundary between these belts. Postmetamorphic faulting at the boundary is probably negligible in this area; the role of plutonism, sediment source and premetamorphic structure are under study.

A byproduct of the study was the discovery that metamorphic plagioclase in low- and medium-grade rocks probably exists in two exsolved phases (collectively called peristerite) averaging near An8 and Ar7. The phases are submicroscopic and were detected by X-ray diffraction.

Comparison of the preliminary geologic map of the Gold Hill quadrangle (loc. 18) in west-central North Carolina and the simple Bouguer gravity map of Watkins and Yuval, 21 the aeromagnetic map of Henderson and Gilbert, 22 and the unpublished radiometric map of this area suggests a good correlation between the areal geology and the geophysics according to H. W. Sundellius. The Silver Hill-Gold Hill fault zone is well delineated by a zone of northeast-trending magnetic highs and lows. This zone of magnetic anomalies separates magnetic patterns characteristic of the relatively undeformed slate belt rocks east of the fault zone from contrasting patterns associated with the more deformed and metamorphosed Charlotte belt rocks west of the fault zone. Relatively narrow, northwest-trending Triassic(?), diabase dikes within the slate belt show up well on the aeromagnetic map. A foliated quartz monzonite body along the upthrown side of the Gold Hill fault correlates with radiometric, magnetic, and gravity lows. In addition, the contact between this quartz monzonite stock and a gabbro-diorite complex is well defined by a strong increase in the magnetic gradient associated with the gabbro-diorite complex. A 2.5-mile long, lenticular metagabbro intrusive in the slate belt is well outlined by a radiometric low. Finally, pyroclastic units within the Flat Swamp Member of the Cid Formation along the limbs of the southwest-plunging Denton anticline are reflected by radiometric lows.

Possible Triassic faults in the Carolina Piedmont

Long rectilinear zones of silicified fault breccia and gneissic wall rocks that were found by J. B. Hadley and A. E. Nelson in Greenville and Spartanburg Counties, S.C., and Polk County, N.C. (loc. 19), probably are due to regional postmetamorphic fracturing and silicification probably during the Triassic. These nearly parallel fracture zones trend east-northeast for distances ranging from a few miles to nearly 30 miles and range in width from a few feet to more than 50 feet. Some occur along the Blue Ridge front, where they form indistinct drainage lineaments. The thicker and more silicified fracture zones in the Piedmont form persistent low ridges. By analogy with similar

occurrences in North Carolina and New England, they are related to the regional faulting that accompanied the deposition of Upper Triassic sediments throughout the Appalachian region.

**Geophysical study of the eastern continental margin**

An aeromagnetic survey extending from the Gulf of Maine to the tip of Florida was conducted by the U.S. Naval Oceanographic Office between 1964 and 1966. The survey traversed part of the Piedmont and Coastal Plain provinces and extended 200 miles beyond the Continental Shelf into the Atlantic Ocean. Isidore Zietz compiled and interpreted these data with P. T. Taylor and L. S. Dennis (of the U.S. Naval Oceanographic Office). They found that a continuous magnetic high on or near the continental slope from northern Maine southward to the 36th parallel, where the slope anomaly bifurcates. Both branches of the anomaly trend parallel the 850-fathom contour southward to the 31st parallel and then swing westward in a smooth arc, passing under the coast near Brunswick, Ga. South of lat 31° N., the continental slope is not paralleled by a magnetic anomaly. Anomaly patterns suggest that rocks much like those exposed in the Piedmont extend seaward beneath the Coastal Plain and Continental Shelf as far as the slope anomaly.

It is possible that the continuous slope anomaly marks the edge of the continental mass and is due to igneous rocks which have invaded the crust along a fracture zone marking the edge of the continent. If so, Florida and parts of Georgia were added to the continent in pre-Ordovician time. Seaward from the slope anomaly, the magnetic field is comparatively featureless. Several interpretations are possible, but it seems most likely that in this area the oceanic crust consists of greenstones similar to those dredged from the central valley of the Mid-Atlantic Ridge.

**COASTAL PLAINS**

**Cenozoic vertebrates**

A rare association of land and marine mammals of Pliocene age was discovered at a locality north of Mobile, Ala. (loc. 14) by J. E. Davis, Jr., a student at the University of South Alabama. The fauna, identified by F. C. Whitmore, Jr. (U.S. Geological Survey), and the late Remington Kellogg (Smithsonian Institution), includes the long-beaked porpoise *Pomatodelphis inaecuialis* Allen; the horse *Hipparion cf. H. plicatilis* (Leidy); *Synthetoceras* sp., an extinct browsing ungulate characterized by peculiar hornlike growths on the skull: a fairly large camel; and a large soft-shelled turtle. The bones occur in clay that is probably of estuarine origin, judging from the presence of a porpoise in association with large logs and many leaves. The land mammals indicate a middle Pliocene age. The porpoise species has also been found in phosphate pits in Polk County, Fla, where it is uncertain whether the specimens are in beds of Miocene or Pliocene age. The genus *Pomatodelphis* is also found in Europe, where it is limited to the Helvetian (middle Miocene). The Alabama fauna is either in the basal Citronelle Formation, or in the Graham Ferry Formation which Brown and others described as underlying the Citronelle in southeastern coastal Mississippi.

The collection of a lower molar of the Pliocene horse *Hipparion cf. H. eurystyle* from the Yorktown Formation at Cobham Wharf, Va. (loc. 15), was reported previously. W. C. Blow, who collected the specimen, informed Whitmore that the specimen was found on the beach at Cobham Wharf. The low bluffs behind the beach at the locality contain exposures (from the base up) of the St. Marys and Yorktown Formations (Miocene), and the Bacons Castle and possibly the Sedley Formations of Coch of Pliocene and (or) early Pleistocene (?) age. The tooth could have fallen to the beach from any of these formations.

**Geochronology of Cretaceous and lower Tertiary strata in New Jersey**

J. D. Obradovich determined K/Ar ages of 33 samples of glauconite collected by J. P. Owens from carefully identified stratigraphic units in the Coastal Plain of New Jersey. N. F. Sohl determined the paleontologic ages of the same units. The results are very consistent. They date the Eocene-Paleocene boundary between 53.7 and 56.1 m.y.; the Paleocene-Maestrichtian boundary between 61.1 and 63.1 m.y.; the Maestrichtian-Campanian boundary at about 63.8 m.y.; and the Campanian-Santonian at about 81 m.y.

**Stratigraphic and geochronologic studies of the northern Atlantic Coastal Plain**

Analysis of onshore and offshore information by T. G. Gibson shows that the largest volume of sediments was deposited before the Late Cretaceous. The Eocene and Oligocene were times of mobility in the depositional areas but there was no large influx of sediment from the source areas. The rate of sedimentation increased in the Miocene, and there was considerable shifting of loci of deposition during this epoch. Volcanic material is widespread in the middle Miocene.
and in the latest early Eocene strata. Volcanic mineral suites are found in Eocene deposits from Long Island southward to the Gulf Coast and in the Caribbean. The source of the volcanic material is uncertain at present.

**Stratigraphy and structure of the Coastal Plain in Georgia**

Subsurface studies by R. C. Vorhis show that the area of Miocene outcrop in Worth, Turner, Crisp, Wilcox, and Ben Hill Counties (loc. 16) is a basin filled with upper Eocene, Oligocene and Miocene sediments. The basin is roughly 25 miles across and has nearly 400 feet of relief on the top of the Ocala Limestone of Eocene age and about 150 feet on the top of the Suwannee Limestone of Oligocene age. The west edge of the basin is formed by limestones that strike north-south. Dips are eastward at about 60 ft per mi on the top of the Ocala Limestone and about 38 ft per mi on the top of the Suwannee Limestone. The basin is not evident on structure contour maps of the tops of the middle Eocene, lower Eocene, Paleocene or Cretaceous. It is therefore more probably depositional than tectonic in origin.

In tracing the sand beneath the Tivola Tongue of the Ocala Limestone, S. M. Herrick discovered a significant gap in northern Montgomery and Toombs Counties (loc. 17). There both the limestone and basal sand are missing or much reduced in thickness. This gap is regarded as the northeastern extension of the so-called Suwannee Strait, a buried valley formed and subsequently filled with sediment during Oligocene time. Its southwestern extension into Florida has been previously noted by Herrick. 26

**Clayton Formation in Tennessee**

Geologic mapping in western Tennessee by W. S. Parks, and others, showed that the Clayton Formation of Paleocene age (loc. 18) changes facies from offshore to nearshore shallow-water marine environments. In southeastern Hardeman County the Clayton consists of glauconitic and fossiliferous sand and clay and a lenticular basal limestone. Northward in eastern Hardeman County this facies intertongues with sand and clay which, for the most part, is nonglauconitic and nonfossiliferous. This latter facies of the Clayton closely resembles lithologies in the upper part of the McNairy Sand Member of the Ripley Formation of Cretaceous age. Consequently, the boundary between the Clayton and the underlying McNairy is not recognized with certainty north of the McNairy-Chester County line.

For the purpose of studying the regional relationships between the Clayton and the McNairy across the State, 6 test holes spaced about 20 miles apart along the outcrop belt were drilled through the Clayton interval. Although the Clayton was not distinguishable in the test holes on the basis of lithology alone, correlation of the electric and gamma-ray logs showed that the Clayton changes facies and indicated that the formation extends across the state.

**CENTRAL REGION AND GREAT PLAINS**

**KENTUCKY**

**Geologic mapping of State**

A cooperative project with the Kentucky Geological Survey begun in 1960 was nearly 60 percent completed by June 30, 1969, when maps of about 310 quadrangles were published and 50 more approved for publication (fig. 1). Kentucky includes all or parts of 763 quadrangles (7.5 minute). Geologic maps are printed on recent editions of topographic base maps of those quadrangles, at 1:24,000 scale, and published in the Geologic Quadrangle Map series.

**Figure 1.**—Published geologic quadrangle maps of Kentucky as of July 1, 1969. Small squares are 7.5-minute quadrangles.

Economic results of the geologic mapping have been varied but impossible to assess fully. Mineral exploration in central and western Kentucky has been stimulated by published maps of faulted areas, resulting in discoveries of fluor spar. Oil and gas exploration, including drilling, has followed such leads on the maps as limestone reefs, sandstone-filled channels, and faults and folds. Limestone quarries have been opened in eastern Kentucky where previously unknown deposits were shown on the maps, and clay deposits in westernmost Kentucky are being leased as maps are published showing their locations.

A short report that followed mapping of several quadrangles in the Western Kentucky coal basin

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showed that erroneous correlations of coal beds had resulted in stopping exploration drilling in fault blocks above a seam mined in the region for stoker and coking coal. As the coal bed is within minable depths, further exploration will probably add several million tons to the largely depleted reserves of that coal bed. According to several reports, maps of eastern Kentucky have led to opening mines in coal beds where coal had been overlooked and thought to be absent.

Perhaps the greatest use of the geologic maps is in the field of construction engineering. Several formations in the state are notoriously unstable for foundations or for use as fill material. These include loess (Pleistocene), mixed loess—which is largely silt—and clay along larger streams, and the Porters Creek Clay (Paleocene) in western Kentucky. One segment of a new highway was recently routed to avoid the Porters Creek Clay shown by mapping to be subject to slumping. In central Kentucky, clay shale in Ordovician and Silurian strata and in the lower part of the Borden Formation (Mississippian) are equally troublesome. Interbedded shale and limestone in western and central Kentucky and interbedded shale and sandstone in eastern Kentucky are subject to sliding on steep dip slopes or near faults excavated by construction activities or undercut by streams.

**OKLAHOMA**

*Fossils of Early Pennsylvanian (Morrow) age from Jackfork Group*

Mackenzie Gordon, Jr., reported that a mold fauna from the Game Refuge Formation at the top of the Jackfork Group of Harlton yielded fossils of Early Pennsylvanian (Morrow) age. The fossils were collected near the type locality of the Wesley Shale of Harlton in Atoka County, Okla. (locality 1, index map), and include such typical brachiopods and trilobites of the Morrow Series as *Hustedia miseri* Mather, *H. brentwoodensis* Mather, *Paladin morrowensis* (Mather), and *Ditymopyge convayensis* Wheeler.

In recent years, many geologists working in Oklahoma have regarded the Jackfork Group as Mississippian in age because of the widespread belief that in places the overlying Johns Valley Shale contains Late Mississippian fossils. The age of the Game Refuge fossils is in agreement with earlier evidence as given by Gordon in Stone  that in Arkansas, at least, the uppermost Stanley Shale, the Jackfork Sandstone, and the Johns Valley Shale are Early Pennsylvanian (Morrow) in age. Precise dating of the flysch deposits in the Ouachita geosyncline (the Game Refuge fossils are from the southwest end of the geosyncline) brings a clearer perspective of the relation of the flysch deposits to the shelf deposits along the north edge of the geosyncline.

**KENTUCKY AND INDIANA**

*Silurian-Devonian stratigraphy and corals*

Colonial rugose corals from the Jeffersonville Limestone at the Falls of the Ohio, near Louisville,  by W. A. Oliver, Jr. The vertical distribution of coral species fits into and clarifies the zonation proposed earlier based on a general survey of the megafossils and provides additional information on regional correlations. The lower 4 feet of the Jeffersonville is Lower Devonian (Emsian) and is correlative with the Bois Blanc and Schoharie Formations in New York. The succeeding “coral” and “stromatoloid zones” correlate with Zone C (coral zone) of the Columbus Limestone in Ohio and the Edgecliff Member of the Onondaga Limestone in New York. The “Spirifer gregarius” zone in Kentucky and Ohio ties in to the middle part of the Moorehouse Member

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of the Onondaga Limestone in New York. The "Spiri-
fier accuminatus" zone in Kentucky is apparently
equivalent to the upper Moorehouse and Seneca
Members in New York and to the upper Columbus
Limestone (Zone H) and Delaware and Dundee Limes-
stones in Ohio. The Jeffersonville Limestone represents
a much less complete record than does either the Co-
lumbus or Onondaga Limestone.

MICHIGAN

Presque Isle Granite

Recent geologic mapping by V. A. Trent in the
north-central part of the Marcellus quadrangle in the
northern peninsula of Michigan (loc. 3) indicates that
pegmatitic Presque Isle Granite intruded and meta-
morphosed by dynamic and thermal processes clastic
metasedimentary rocks interpreted to be equivalent to
the Palms Quartzite. The clastic metasedimentary
rocks crop out south and southeast of the center of sec.
21, T. 47 N., R. 43 W. and appear to underly conform-
able typical Palms Quartzite exposed near the center
of the section. Within half a mile of the granite, these
rocks have been changed to paragray schist and paragneiss
in which the effects of potash metasomatism are evi-
dent.

Sulfide-bearing dikes in Gogebic area

Dark sulfide-bearing mafic, mostly dikelike, rocks
are common in the older Precambrian rocks of the
Gogebic area (loc. 4), according to R. G. Schmidt and
V. A. Trent. Although there is a considerable range in
composition, age, texture, and degree of meta-
morphism, most rocks are hornblende rich, generally bear
pyrite, and are moderately metamorphosed; some are
fairly large masses.

Most of the older dikes trend eastward; the younger
dikes trend northeastward or northwestard; the
youngest dikes are locally unmetamorphosed.

Interest developed when sulfides were discovered in
many of the larger masses, the largest being at least
600 feet by, perhaps, 3,000 feet. Semiquantitative spec-
 trographic analyses and atomic-absorption-spectrome-
try determinations indicated that copper, nickel, co-
obalt, and silver contents are low everywhere. The
maximum sulfide content is several percent, and it was
concluded that none of the bodies is of economic inter-
est.

WISCONSIN AND MINNESOTA

Reinterpretation of Douglas thrust fault of northwestern
Wisconsin and adjacent Minnesota

Recent reconnaissance in the Douglas Range in
northwestern Wisconsin (loc. 5) by H. A. Hubbard
suggests that the volcanic rocks of the range are not
bounded, by a thrust fault as had been generally
thought. Hubbard's interpretation is that the volcanic
rocks lie unconformably upon folded sedimentary
rocks, and both the volcanic rocks and folded sedimen-
tary rocks are unconformably overlain by horizontal
sandstone of the Hinckley Sandstone of Winchell 32
and the Bayfield Group in Minnesota and Wisconsin.

Although exposures are sparse, flat-lying sandstone
overlies steeply dipping volcanic rocks along the Ket-
tle River in Minnesota. In several places, the base of
the volcanics is discordant above steeply dipping sedi-
mentary strata which crop out between volcanic rocks
and the horizontal sandstone. These unconformities are
exposed at Amicon Falls, Wis. The presence of a
thrust fault had been based in large part on the inter-
pretation that the steeply dipping sedimentary rocks
are stratigraphically equivalent to the horizontal sand-
stone, and that pebbles of volcanic rocks in the steeply
dipping sedimentary rocks were derived from the over-
lying volcanic rocks. The pebbles in the steeply dip-
ning sediments are predominately felsic volcanic rocks,
whereas the overlying volcanic rocks appear to be pre-
dominately intermediate to basic.

MINNESOTA

Sand and gravel along Mesabi Iron Range

Sand and gravel deposits along the Mesabi Iron
Range, Minn., are being correlated through analysis of
data from drill holes and exposures in iron mines. Ac-
cording to T. C. Winter the most conspicuous unit, con-
sisting of very clean medium sand to coarse gravel, oc-
curs along the iron range from near Chisholm westward 20 miles to Pengilly (loc. 6). Its southward
extent is unknown. Other large sand and gravel depos-
its, many covering several square miles, occur in this
area, but their size and shape are not well known.

NEBRASKA

Late Miocene diatoms in Valentine Formation

The Valentine Formation of Lugn 32 near Kilgore,
Cherry County, Nebr. (loc. 7) contains late Miocene
diatoms and plants. These diatomaceous sediments
were dated as latest Miocene by an earlier study of
their flora and, in addition, of a vertebrate fauna in
correlative strata near Valentine, Nebr. The Kilgore
diatom assemblage, according to G. W. Androws, con-
336-337.

32 Winchell, N. H., 1886, Revision of the stratigraphy of the Cambri-
398-337.

33 Lugn, A. L., 1938, The Nebraska State Geological Survey and the
220-227.
diatomaceous beds were deposited in a small, relatively shallow lake of hard water, which at times became somewhat alkaline or saline.

Five presumably extinct species of diatoms may prove to be diagnostic in stratigraphic correlations. The diatom assemblage is stratigraphically important, as its position close to the Miocene-Pliocene boundary serves to provide criteria for distinguishing nonmarine Miocene and Pliocene strata in the Great Plains.

Pre-Quaternary drainage in southeastern Nebraska

Subsurface studies and reconnaissance mapping of the Lincoln and Nebraska City 1:250,000-scale quadrangles, southeastern Nebraska, show that the buried pre-Quaternary drainage is very different from that of the present, according to G. E. Prichard. (U. S. Geological Survey) and coworkers E. C. Reed, V. H. Dreeszen, and R. R. Burchett (Nebraska Conservation and Survey Division). Geologic maps of Nebraska will show bedrock geology and thickness of Quaternary overburden.

MONTANA

Geophysical evidence of Precambrian basement

Aeromagnetic and gravity maps of central and eastern Montana suggest, according to Isidore Zietz, B. C. Hearn, Jr., and Donald Plouff, that several linear fault zones which extend from the surface into the Precambrian basement are boundaries between basement terrains of differing structure, lithology, and abundance of plutons. These zones are the three major east-southeast trending lineaments of central Montana (Nye-Bowler, Lake Basin, and Cat Creek-Porcupine Dome), and the northeast-trending Brockton-Froid and Weldon fault line of northeast Montana. Another geophysical boundary in the basement, indicated by the maps, appears to extend from the northeast flank of the Black Hills uplift to the east side of Porcupine Dome.

A northwesterly trend of magnetic anomalies and the axis of the Cedar Creek anticline appear to end approximately at the line of the Brockton-Froid fault zone and Weldon fault. Northwest and west of those faults the magnetic and gravity anomalies, and the assumed structural grain of the basement, trend markedly northeastward. A similarly pronounced northeast magnetic grain occurs in the block between the Lake Basin and Nye-Bowler fault zones, and a weaker grain is shown by the magnetic pattern north of the Lake Basin fault zone. South of the eastward projection of the Nye-Bowler fault zone the predominant magnetic grain is northwestward.

NORTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Lead-silver in the Gilmore district, Idaho

The lead-silver deposits of the Gilmore mining district, Lemhi County, Idaho (locality 1, index map), are mainly replacement deposits in carbonate rocks along steep, north-trending veins. Geologic mapping by E. T. Ruppel indicates that the principal deposits are all in the Jefferson Formation (Devonian), although smaller deposits are also known in the underlying Ordovician dolomite and the overlying Mississippian rocks. All the known deposits are peripheral to a buried quartz diorite stock. The stock and the surrounding host rocks most favorable for mineralization are buried beneath glacial deposits, alluvial fans, and pediment gravels north of the main Gilmore area. Geochemical and geophysical prospecting in this area could lead to discovery of concealed lead-silver deposits.

Possible phosphate near Henrys Lake, Idaho

Two tilted fault block mountain ranges converge in the Idaho-Montana border area north of Henrys Lake, (loc. 2)—the northwest-trending Madison Range and the east-trending Centennial Range. Although the complex structural relations have not yet been completely worked out, geologic mapping by I. J. Witkind demonstrated that the same sedimentary units are exposed in each range. Thus the Permian stratigraphic interval that contains important phosphate deposits in the Centennial Range is also exposed in the Madison Range, where very little prospecting has been done.
Large gypsum reserves in central Wyoming

Compilation of stratigraphic data on Jurassic rocks in central Wyoming by J. D. Love and L. W. McGrew indicates that a gypsum and anhydrite bed, ranging in thickness from 30 to 125 feet and averaging 70 feet, occurs in the Gypsum Spring Formation (Middle Jurassic) in an area of about 2,000 sq mi in the western part of the Wind River Basin (loc. 3). Total tonnage (surface and subsurface) of gypsum and anhydrite is estimated to be about 350 billion tons, and despite surface leaching, an estimated 600 million tons of “sugar crystal” gypsum may lie within 100 feet (downdip) of outcrops along 150 linear miles.

WESTERN BELT BASIN

New stratigraphic data on upper part of Belt Supergroup

Extensive exposures of the upper part of the Belt Supergroup were mapped by A. B. Griggs in the area south of Coeur d'Alene Lake and west of the St. Maries River in northern Idaho (loc. 4). The strata include about 5,000 feet of the upper Wallace Formation, about 5,000 feet of the Striped Peak Formation, and about 5,000 feet of the Libby Formation. All units show slight facies changes from equivalent strata that crop out several miles away to the north and east. The thicknesses of the Striped Peak and Libby Formations are the largest known in northern Idaho.

Thrusts across the Purcell trench

Parts of the Prichard Formation have been thrust eastward across the Purcell trench near Elmira, Idaho (loc. 5). Preliminary interpretation by J. E. Harrison suggests that the thrusts are part of the eastern edge of the Kootenay Arc mobile belt. More specifically, they formed during an early stage of the emplacement of the Kaniksu batholith which forms the western edge of the Purcell trench in the Idaho panhandle. Porphyritic granodiorite was intruded into the thrust plates during later stages of batholith emplacement. The thrusts are now exposed either in large roof pendants of Prichard rocks or near the edges of the granodiorite masses.

Aeromagnetic map aids interpretation of complex fault pattern

An aeromagnetic survey of an 800-sq-mi area (loc. 6) in northern Idaho, east of the Purcell trench and south of the Hope fault, clearly delineates surface and near-surface stocks and cupolas of granodiorite intruded into the Belt rocks. E. R. King, J. E. Harrison and A. B. Griggs found that the aeromagnetic anomalies are principally a reflection of these granodiorite masses, which are inferred to be parts of a larger mass underlying most of the area at depth. The reticulrity of some of the aeromagnetic contours reflects major faults that are the boundaries of large blocks which moved during tectonic swelling and emplacement of the granodiorite. Subsequent collapse along numerous minor faults created a block mosaic. The Magee fault zone, for example, consists of numerous closely spaced, high-angle faults recording collapse of a monoclinal flexure formed when a long narrow pluton raiired and tilted a block bounded on the west by the Cascade fault. The major faults are part of a north-trending zone of weakness that corresponds in part with the Purcell trench. The zone has helped localize intrusion as well as later erosion that exposed some of the intrusives. Many of these major faults are reflected in the magnetic pattern by elongate lows.

MONTANA DISTURBED BELT

Gravitational gliding will explain northern part of the disturbed belt

Vertical uplift and accompanying gravitational gliding is a feasible explanation for the structures in the disturbed belt in northwestern Montana (loc. 7), according to studies by M. R. Mudge. Westernmost Montana was uplifted during the Jurassic and Cretaceous, and recurrently into the very early Tertiary. Abnormal fluid pressures may have developed in the easterly tilted sediments, a décollement was established in mudstones under an overburden of about 25,000 feet of rock, and the mass glided eastward across a small Mesozoic basin. The décollement migrated up section to the east. The folded east edge of the disturbed belt is probably controlled by the erosional edge of the Precambrian Belt rocks and the west edge of the craton. Additional uplift in the west continued to produce sliding that piled one fault block upon another. Aggregate uplift to the west exceeded 45,000 feet.

Large Basin and Range type normal fault developed, after thrusting, between the area of maximum uplift and the thrust-fault belt. The westernmost of these faults formed the graben and horsts in the Rocky Mountain trench. Normal fault displacement along one line of section is about 43,000 feet, whereas the computed thickness of strata eroded from the area of maximum uplift is about 45,000 feet.

Faults change habit from range to basin

Major cross faults of the Bridger Range (loc. 8) become near-bedding faults in strata of the Livingston Group (Upper Cretaceous) northeast of Bozeman, Mont., according to B. A. Skipp. These faults are interpreted as décollement surfaces formed during late
Paleocene east-directed thin-skinned deformation; the thrust faults have been bent up by later Tertiary block uplift.

Positive magnetic anomalies reflect edge of the disturbed belt

Magnetic studies by M. D. Kleinkopf in the northern Montana Rockies (loc. 9) show a 1,500-gamma positive anomaly over the Blackfeet Indian Reservation. This is another of a series of high-amplitude positive anomalies located at the edge of the High Plains which seem to reflect discrete masses of intermediate to mafic rocks in the crystalline basement along the disturbed belt—other similar anomalies are near Dupuyer and north of Choteau, Mont.

Remanent magnetization in volcanic rocks along the disturbed belt

Upper Cretaceous glassy volcanic rocks near Wolf Creek and Sappington, Mont. (loc. 10), possess intense stable remanent magnetization despite severe tectonic deformation, according to W. F. Hanna. Both glassy units have reverse magnetization, as do devitrified welded tuffs stratigraphically above and below the units at each site. Although the sites are more than 100 km apart and have different structural attitudes, the rocks at both rest on major overthrust soles of Precambrian rocks and yield similar potassium-argon ages. The directions of reversed remanent magnetization of both units, after structural correction, are in general agreement with those previously determined for the Elkhorn Mountain volcanic field to the west.

YELLOWSTONE NATIONAL PARK AND VICINITY

Prevolcanic sedimentary rocks

The major structural features in the prevolcanic sedimentary rocks in south-central Yellowstone National Park Wy-o.-Mont.-Idaho (loc. 11), and adjacent areas emerged from geologic mapping and related stratigraphic studies by W. R. Keefer and J. D. Love. The field relations indicate that the present structural pattern of the region, established during latest Cretaceous and early Tertiary, includes: (1) a broad uplift to the west, (2) a central downwarp in which several thousand feet of uppermost Cretaceous and lower Tertiary sediments accumulated and then were later folded into a large anticline, and (3) a westward-moving thrust block on the east that overrode the east flank of the depositional basin. These structures are continuations of major structural elements in Jackson Hole and adjacent mountain ranges to the south. Their large amplitude and areal extent suggest that originally they may have continued northward across the central Yellowstone region and connected with similar structures in the sedimentary rocks along the margin of the Park.

These structures were modified extensively by later episodes of uplift, subsidence, normal faulting, and volcanism. The volcanic sequences are involved in the normal faulting in some places.

Volcanic evolution of the Yellowstone Plateau and eastern Snake River Plain

Continuing work on the Yellowstone Rhyolite Plateau and vicinity by R. L. Christiansen and H. R. Blank, Jr., has now outlined the major features of its volcanic evolution. The plateau centers around two resurgent calderas that are about 30 and 20 miles across, related to the eruption of ash-flow sheets about one million years old and half a million years old. The calderas are partly filled by rhyolitic lava erupted from their ring-fracture zones. The ash-flow sheets on the flanks of the plateau are interlayered with tholeiitic basalts. Island Park, southwest of the Yellowstone Plateau, consists of two overlapping collapse areas that are related to eruption of two lower Pleistocene ash-flow sheets, the younger of which is about 112,000 years old. Tholeiitic basalts were erupted on the floor of Island Park caldera but not during its period of rhyolitic activity.

The history of the Yellowstone Plateau and Island Park, together with evidence from the eastern Snake River Plain and its margins, suggests that the eastern plain was the site of earlier large rhyolitic centers associated with voluminous ash-flow sheets, large calderas, and postcollapse rhyolitic lavas. Tholeiitic basalts preceded formation of the rhyolitic centers and were erupted on their flanks as they evolved, but tholeiitic, and finally, more alkali-rich basalts that flooded the downwarped axis of the plain represent the culmination of volcanism after final consolidation of the rhyolitic magmas.

Remanent magnetism aids geologic dating of Yellowstone volcanics

Geologic mapping and field polarity measurements by H. R. Blank, Jr., and R. L. Christiansen identified three stratigraphic zones in the Yellowstone area in which a near-horizontal geomagnetic field direction is recorded by remanent magnetism of the rocks. Two of these zones are at the top and base of a composite ash-flow tuff sheet and represent the onset and close of an episode of eruption of Yellowstone tuffs. Eruption of this sheet may exactly bracket the Jaramillo normal polarity event in the Matuyama reversed polarity epoch. Preliminary K-Ar sanidine dates by J. D. Obradovich from lavas interbedded with Yellowstone tuff cooling units are compatible with this hypothesis.
Origin of the Absaroka volcanics as indicated by lead and strontium isotopes

An investigation into the petrogenesis of the Eocene Absaroka volcanic rocks in Yellowstone Park using Pb and Sr isotopes as tracers was made by H. J. Prostka, B. R. Doe, and Z. E. Peterman. Fourteen samples, mainly of potassic basalt (shoshonite and absarokite) and calc-alkaline andesite, have Sr\(^{87}/Sr\(^{86}\) ratios ranging from 0.7045 to 0.7093. From a single vent, one andesite and four shoshonites have uniform Sr\(^{87}/Sr\(^{86}\) values (0.7045 to 0.7049) indistinguishable from oceanic basalts. The volcanics have unradiogenic lead isotopic compositions with Pb\(^{206}/Pb\(^{204}\) values ranging from 16.34 to 17.30. A combination of these data with trace-element and petrographic information indicates that upper crustal contamination did not play a significant role in the formation of these rocks. Instead, the lavas were probably derived by partial melting of an isotopically nonuniform source in the lower crust or upper mantle which attained its U/Pb and Rb/Sr heterogeneity approximately 2,800±200 m.y. ago; very little mixing of the Pb and Sr isotopes occurred in the derived melts prior to eruption. The age of 2,800±200 m.y. obtained from the anomalous Pb line suggests a genetic tie between the source rocks and the upper crust in this region.

Research drilling continues to yield valuable data on thermal waters

The Yellowstone Park research drilling program whose results are being analyzed by D. E. White, R. O. Fournier, L. J. P. Muffler, and A. H. Truesdell, was recessed November, 1967, after completion of 10 drill holes, totalling 4,901 feet. Drilling was resumed May 13, 1968, and completed July 17, 1968. Summary data for the 1968 drilling follows:

<table>
<thead>
<tr>
<th>Number</th>
<th>Location</th>
<th>Depth (ft)</th>
<th>Max. temp. (°C)</th>
<th>“Over-pressure” (psi)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-12</td>
<td>Porcelain Terrace, Norris Basin</td>
<td>1,088</td>
<td>240</td>
<td>38 (all water over-pressure), 180 (~105 water over-pressure).</td>
<td>Ash-flow tuff.</td>
</tr>
<tr>
<td>Y-13</td>
<td>Porcupine Hills, Lower Basin</td>
<td>465</td>
<td>204</td>
<td>180 ( ~105 water over-pressure), 300 ( ~150 rhyolite flow).</td>
<td>Sediments and rhyolite flow.</td>
</tr>
</tbody>
</table>

All three drill holes provided highly significant dividends for subsurface interpretations. Y-11 evidently penetrated into a dry steam system, modified near the surface and on cooler borders by condensation of steam to liquid water. This was the only “dry steam” system found in 13 holes, and was anticipated from interpretation of the hot-spring fluid compositions. The deepest hole, Y-12, encountered the highest temperatures for its depths yet found in research or commercial geothermal drilling. Drilling to the attained depth and temperature was possible only because pressures and permeabilities were relatively low. Y-13, however, had to be terminated at only 465 feet because of very high water overpressures.

The accuracy of a calculated reference boiling point curve (temperature of boiling versus depth in a column of water, all just at boiling) was verified by many of the drill holes, but never more convincingly than by Y-13. All data points between 50 ft and 450 ft, if actual depth is corrected for equivalent water overpressure, had temperatures that plotted within 1° or 2°C of the calculated reference curve.

Primary temperatures were obtained in 1-2 holes as drilling progressed, generally after about 16 hours of layover since previous drilling. These measured temperatures are generally within about 2°C of original ground temperature prior to drilling. The drill hole, after completion, provides a “short-circuiting” permeable channel that intersects many natural channels of differing temperature and pressure. Temperature profiles obtained in drill holes after completion and attainment of steady state prove that great changes can be induced by some holes. Throughout the world, geothermal wells are customarily drilled on a 2- or 3-shift per day basis, and all temperatures are obtained in completed holes. Such temperature curves may have attained steady states, if measured sufficiently long after completion of drilling, but the Yellowstone data show that these measured temperatures may bear little relation to original ground temperatures. These findings may have major significance in the interpretation of deep commercial drilling for geothermal energy.

Geologic history of the Grand Canyon of the Yellowstone

The history of the Grand Canyon of the Yellowstone River, as interpreted by G. M. Richmond and R. L. Christiansen, begins with the overflow of a caldera lake which cut the northern sector of the canyon. A large rhyolite flow in the caldera blocked the canyon entrance, but the lake rose across the flow and regained its former outlet into the canyon. The canyon was then extended headward across the flow to the position of the Lower Falls by erosion along a zone of fumarolic alteration, from which the term “yellow stone” is derived. A middle Pleistocene iccap overrode the canyon and lake beds and nearly filled the canyon’s upper sector during recession of the ice. About 150,000 years ago, a rhyolite flow overran the uppermost reach of
the canyon, diverting the river to its present position above the Upper Falls. In late Pleistocene time, the canyon was filled and overridden, but not eroded, by both Bull Lake and Pinedale icecaps.

**Bull Lake glaciers twice the size of Pinedale glaciers**

Although Bull Lake glaciers were only slightly larger than Pinedale glaciers in most of the northern Rocky Mountains, K. L. Pierce reported that relict soil profiles near Gardiner, Mont., indicate that Bull Lake outlet glacier from the Yellowstone iccap was more than twice as thick as the 1,000-foot-thick Pinedale one. In addition, although the Pinedale icecap lapped against the flanks of the Washburn Range, striations along the crest indicate that older ice, probably Bull Lake in age, flowed northward across the Range about 1,500 feet above the level of the Pinedale icecap. Because the axis of the Bull Lake icecap was 10 to 15 miles west of the Pinedale one, the western part of the Park was much more affected by Bull Lake Glaciation than by the Pinedale. The more westerly extent and higher level of the Bull Lake icecap could well have been due to longer duration of full-glacial conditions; for the icecap, once established on the Yellowstone Plateau, would lead to increasingly greater snow accumulation and would build preferentially towards the western source of moisture.

**Oligocene age of Wiggins Formation and late basic breccia**

Recent structural studies of Jackson Hole and southern Yellowstone National Park have defined an episode of large-scale normal faulting that involved 1,000-2,000 feet of collapse of the Washakie Range. The amount of offset has been measured in younger volcanics, the Wiggins Formation and the late basic breccia, that buried the range. A cooperative investigation by J. D. Love of (U.S. Geological Survey) M. C. McKenna (American Museum of Natural History), and M. R. Dawson (Carnegie Museum), resulted in collection and identification of 13 genera and 6 species of mammals of early Oligocene (Chadronian) age from the downfaulted basal part of the Wiggins Formation. This is the first diagnostic mammalian faunule of Oligocene age reported from the entire Yellowstone-Absaroka volcanic area. The age determination is significant because it provides clues to the tectonic history, the type of volcanic rock extruded at a specific time, the local environment, and the direction of major river flow near the beginning of Oligocene deposition.

**White Mountain not a volcanic center**

A spire on White Mountain in the southeastern corner of the Beartooth Butte quadrangle, Wyoming (loc. 18), within the Absaroka volcanic field, has been considered to be the remnant of a filled volcanic conduit. Recent work by W. H. Nelson showed this spire to be, instead, a remnant of the Cathedral Cliffs Formation which is composed largely of volcanioclastic rocks of Eocene age, and which is part of a Heart Mountain fault block.

**SNAKE RIVER PLAIN**

**Bonneville flood in Snake River Plain**

The colossal features of erosion and deposition produced along the Snake River in Idaho (loc. 15) by sudden overflow of Lake Bonneville about 30,000 years ago, according to H. E. Malde (1876), indicate that as much as 380 cu mi of water discharged at Red Rock Pass at a maximum rate of about one-third cu mi per hr. The Canyon of the Snake in southern Idaho was flooded to a depth of 300 feet, and more than a half a cu mi of bouldery debris was deposited in basins along the canyon where floodwater was temporarily held by hydraulic dams. A major part of this debris was eroded from the canyon near Twin Falls, a scenic stretch marked by abandoned spillways, cataracts, and scabland.

**Ground-water geophysics near Arco, Idaho**

Resistivity soundings, seismic refraction, and gravity surveys north of Arco, Idaho (loc. 14), by A. A. Zohdy proved to be of significant value in delineating the Paleozoic bedrock configuration along two profiles. In addition, information on the top and bottom of buried lava flows was obtained from the resistivity and seismic refraction profiles. This information is useful for management of the limited ground-water supplies in the area.

**REGIONAL STRATIGRAPHY**

**Marked facies changes described in lower Miocene Cambrian rocks**

Recognition of a Middle Cambrian outer detrital belt, a middle carbonate belt, and an inner detrital belt, represented by marked contrasts in facies has been masked in southeastern Idaho by indiscriminate regressions and regressions comparable to those recognized in Cambrian rocks in other parts of the Cordilleran region. A new rock-stratigraphic classification is being proposed by S. S. Oriol and F. C. Armstrong to emphasize contrasting rock types and to facilitate understanding of genesis.
New hope for Cambrian and Ordovician correlation across Snake River Plain  

Work in the Bayhorse district of east central Idaho (loc. 16) by S. W. Hobbs, W. H. Hays, and R. J. Ross, Jr., disclosed over 10,000 feet of quartzite, slate, dolomite, and limestone that are probably all of Cambrian or Early Ordovician age. Rocks approximately equivalent to these in age and total thickness occur in the Potcatello area of southeastern Idaho. Fossils found thus far are inadequate to permit precise correlation.

Fossil find aids correlation of Mississippian rocks across Snake River Plain  

Fossils recovered by W. J. Sando and W. J. Mapel from the Milligen Formation in the Donkey Hills, Hawley Mountain quadrangle, Idaho, (loc. 17) have an important bearing on the age and correlation of this sparsely fossiliferous unit. Cephalopods from a limestone bed in an argillite sequence about 20 feet below the lowest siltstone beds in the section are of early or middle Osage aspect, according to MacKenzie Gordon, Jr. Cephalopods and brachiopods in siltstone about 70 feet above the top of the argillite are of middle Meramec age. Thus a disconformity may separate the argillite from the overlying siltstone. A comparable situation exists in southeastern Idaho, where siltstone at the base of the Little Flat Formation rests disconformably on the Lodgepole Limestone.

A paleogeologic stopwatch times Late Cretaceous events of Wyoming and Montana  

Potassium-argon dating of biotite from bentonite beds of Late Cretaceous age in the northern part of the western interior region indicates that the Montana Group was deposited during a span of about 15 m.y. During this time the Cretaceous sea contracted and expanded several times as is indicated by the Telegraph Creek-Eagle regression, Claggett transgression, Judith River regression, Bearpaw transgression, and the Fox Hills regression. Paleogeographic maps for this period, based on stratigraphic and paleontologic data collected by J. R. Gill and W. A. Cobb, integrated K/Ar age determinations made by various workers, permit a rough estimate of the duration of transgression and regression and a measure of the distances that the strand moved. The Telegraph Creek-Eagle regression lasted about 5.5 m.y., and the strand retreated eastward as much as 240 miles. The Claggett transgression was short, lasting only about 1.5 m.y., and the strand advanced 140 miles. The Judith River regression lasted about 3 m.y., and the strand retreated about 190 miles. The Bearpaw transgression lasted about 3 m.y., and the strand advanced about 200 miles. The Fox Hills regression was slow at first but rapid towards the end; it lasted about 2.5 m.y., and the strand retreated more than 250 miles.

Lower Tertiary rocks of the Green River Basin  

A tuff bed recognizable because of its unique layering was found near LaBarge, Wyo. (loc. 18), in the northwest part of the Green River basin by W. C. Culbertson and traced along the outcrop for about 35 miles. This tuff lies near the top of the middle tongue of the Green River Formation (Eocene) at its southern exposures, but it lies at the base of this unit at its northernmost exposures. Previously, Culbertson had traced this same tuff across an area of about 2,000 sq mi in the southeastern part of the basin where it lies near the top of the Wilkins Peak Member of the Green River Formation. This find not only permits a more precise correlation, but it also helps clarify the geologic history of the area. For example, the marlstone and oil shale of the middle tongue probably were deposited near the margin of a lake that was slowly transgressing northward across the fluvial deposits of the New Fork Tongue of the Wasatch Formation.

Heavy-mineral suites—A key to Tertiary stratigraphy of the High Plains  

The distinction between subdivisions of middle and upper Tertiary rocks indicated by different suites and proportions of nonopaque heavy minerals is substantiated by vertebrate fossils whose ages match those from the type areas of the formation in the Badlands of South Dakota and the High Plains of western Nebraska. These results are based on a petrographic study by N. M. Denson (p. C25-C32) of about 2,000 heavy-mineral separates from more than 100 stratigraphic sections extending eastward from the Wind River Mountains in western Wyoming to the vicinity of Scotts Bluff National Monument in western Nebraska.

Source of conglomerates in northwest Wyoming  

Paleocurrent directions, roundstone size, and petrographic variables of the conglomerates in the Harebell Formation and Pinyon Conglomerate (loc. 19) are being studied by D. A. Lindsey in order to determine the source, provenance, and depositional environment of these rocks. These indicators show that the conglomerates were derived from source areas west and northwest of Jackson Hole. No obvious differences between depositional features of the conglomerates were detected. However, two geographically distinct conglomerate deposits were identified, one north and one south of the Buffalo River. Within each deposit, polynomial surfaces fitted to maximum roundstone size reveal significant trends which may represent the position of ancient channels.
To better establish the probable source of conglomerates in the Harebell and Pinyon Formations, similar conglomerates north of the Tetons and farther west in the Beaverhead Formation of Idaho were studied. These conglomerates contain quartzite, quartz-bearing volcanics, and other sedimentary clasts identical to those found in the Harebell and Pinyon. Paleocurrent directions in these conglomerates indicate derivations from the west and southwest, possibly from the vicinity of the present outcrops of quartzites of the Belt Supergroup in Idaho.

**SOUTHERN ROCKY MOUNTAINS**

**PRECAMBRIAN ROCKS OF COLORADO**

A melasyenite intrusion in the San Juan Mountains

An alkalic-mafic igneous intrusion occurred in the west-central San Juan Mountains, Hinsdale County, Colo. (locality 1, index map), about 1,400 m.y. ago.

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**SOUTHERN ROCKY MOUNTAIN STATES**

Part of a stock of oversaturated hornblende-biotite melasyenite exposed in an erosional window studied by Fred Barker, Z. E. Peterman, and R. F. Marvin is compositionally similar to potassic lamprophyre and shonkinite. The magma which formed these rocks first crystallized much hornblende and biotite that is deficient in silica relative to augite. The remaining liquid was thus enriched in silica and precipitated small amounts of quartz along with much potassic feldspar. Water content, in stabilizing the hornblende and biotite, effectively caused the formation of an oversaturated rock. An initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio for this rock of 0.7031 compares well with a predicted value for the mantle of 0.7022 and fits a hypothesis of origin of this magma from the mantle.

**Rutile in rocks of varied lithology**

D. M. Sheridan and S. P. Marsh* reported that rutile-bearing Precambrian rocks of varied lithology are found in a seemingly favorable belt extending 16 miles southeast from Santa Fe Mountain in Clear Creek County to the Turkey Creek area in Jefferson County, Colo. (loc. 2). Interlayered and gradational lithologic varieties include feldspathic biotite gneiss, sillimanitic quartz gneiss, topaz-bearing quartz gneiss, and, at one locality, calc-silicate gneiss. Locally, the rutile-bearing rocks contain noteworthy amounts of such minerals as corundum, tourmaline, and garnet. The rutile content of samples from the rutile discovery area ranges from 1.5 to 3 percent. Elsewhere, the rutile content ranges from 0.5 to 2 percent.

**Geochronology**

Alkaline igneous rocks in the Powderhorn district, Gunnison County, Colo. (loc. 3) were reported by J. C. Olson to be of two principal age groups according to analyses by R. F. Marvin. An older group of syenites was dated at about 1,350 to 1,390 m.y., and a younger group from the Iron Hill complex of pyroxenite, carbonatite, and related rocks appears to have formed about 570 m.y., ago.

**MESOZOIC STRATIGRAPHY**

Chinle and Sundance Formations along flanks of Park Range, Colo.

G. N. Pipiringos, W. H. Hail, Jr., and G. A. Irett (1925) studied the Chinle Formation (Upper Triassic) and the Sundance Formation (Upper Jurassic) along the flanks of the Park Range near Kremmling, Colo. (loc. 4). The Chinle on the west side of the range consists of three members that are probably equivalent to the Popo Agie Formation and the Bell Springs Member of the Nugget Sandstone in south-central Wyoming. The Chinle is truncated eastward and, except in a small area northwest of Kremmling, is absent on the east side of the Park Range. The Sundance Formation is thickest along a line extending from Elk Creek, near McCoy, to Frantz Creek, northwest of Kremmling; it is thinnest in the area west of Kremmling. The Canyon Springs Sandstone Member of the Sundance Formation is noteworthy in this area where it changes abruptly from typical massive crossbedded sandstone to mixof sandstone and shale.

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northeast source of sediments in the San Ysidro area of the Morrison Formation, dip south and west. In the adjacent Laguna area, to the southwest, most of the cross beds in the Jackpile dip northeast. This suggests a northeast source of sediments in the San Ysidro area and a southwest source in the Laguna area.

Source directions for "Jackpile" sandstone

In the San Ysidro quadrangle, Sandoval County, N. Mex. (loc. 6), E. S. Santos found that most cross beds in the Jackpile sandstone, an informal unit in the Morrison Formation, dip south and west. In the adjacent Laguna area, to the southwest, most of the cross beds in the Jackpile dip northeast. This suggests a northeast source of sediments in the San Ysidro area and a southwest source in the Laguna area.

STUDIES INVOLVING CENOZOIC DEPOSITS

Tertiary boulder alluvium in Wet Mountains, Colo.

Deposits of boulder alluvium discovered by R. B. Taylor and G. R. Scott permitted partial reconstruction of early and middle Tertiary geomorphic features in the Wet Mountains in south-central Colorado. (loc. 7). The presence of an ancient drainage system was established from remnants of flat-bottomed valleys and their walls, and by boulders of distinctive rock types that can be traced from source areas along alluvial courses. Early and mid-Tertiary streams flowed east or northeast across the northern end of the Wet Mountains. Remnants of a mid-Tertiary erosion surface on the crest of the Wet Mountains are correlated westward with other parts of the same surface that lie 1,200 to 1,500 feet lower. Displacement of this surface took place in the late Tertiary, mostly along the Ilse fault. A considerable part of the present land surface between the Ilse fault and the structural trench of the Wet Mountain Valley coincides with a little-modified surface that was cut in Precambrian rocks during late Eocene and early Oligocene time.

Late Eocene or early Oligocene age of Florissant Lake Beds, Colorado

Mapping in the Florissant, Colo., area (loc. 8) by R. C. Epis revealed a previously undescribed arkosic boulder aluvium that underlies an ash-flow tuff. This alluvium was probably deposited at the same time as the erosion and alluviation that produced the pre-volcanic arkose of the south-central part of the Thirtynine Mile volcanic field. The ash-flow tuff (ryholite of Cross, 34) underlies the Florissant Lake Beds. Field and petrographic evidence indicate that it is one of three older ash flows of the Thirtynine Mile volcanic field. The Florissant Lake Beds are overlain by remnants of intermediate to basic layered breccias and flows that probably correlate with the upper member of the lower andesite of Epis and C. E. Chapin (r0481). Accordingly, the Florissant Lake Beds probably are of late Eocene or early Oligocene age, and appear to correlate, at least in part, with the Antero Formation of South Park of Johnson.

Slide blocks of Paleozoic limestone in upper Tertiary deposits

R. E. Van Alstine found detached blocks of Paleozoic carbonate rocks lying within and adjacent to the San Luis-Upper Arkansas graben between the Sawatch and Sangre de Cristo Ranges southwest of Salida, Colo. (loc. 9). These blocks, too large to have been transported by water, were evidently emplaced by gravitational sliding eastward from the Sawatch Range into this late Tertiary trough. The sediments which filled the trough and enclosed the Paleozoic blocks were tilted west in Pliocene time, and the detached blocks are now being exposed by erosion of the overlying basin fill.

Remnant of late Tertiary surface at south end of Rocky Mountains

A pedimented surface on Glorieta Mesa in the northwest corner of the Laguna Ortiz quadrangle in San Miguel County, N. Mex. (loc. 10), was reported by R. B. Johnson. This surface is capped by 1 to 5 feet of pebbles and cobbles derived from Precambrian rocks in the Sangre de Cristo Mountains 15 miles north. The pedimented surface cuts across the Santa Rosa (Triassic) and Bernal (Permian) Formations and forms an

34 Cross, C. W., 1894, Description of the Pikes Peak sheet [Colo.]: U.S. Geol. Survey Atlas folio (no. 7), 5 p., maps.
isolated mesa 200 feet above the surface of Glorieta Mesa. The surface of the pediment remnant slopes less than 1° south and projects into the Vaughn surface 50 miles southeast.

**STRUCTURE**

**Laramide tectonism in the Kaiparowits region of southern Utah**

A study of the distribution of facies and thickness variations of Cretaceous rocks by Fred Peterson indicates that Laramide deformation occurred in two phases in the Kaiparowits structural basin of southern Utah (loc. 17). An early phase that lasted from about late Albian to late Campanian time included regional subsidence, basin downwarping, and movement on local folds and faults. A later phase that lasted from late Campanian to about late Paleocene time included regional uplift, monoclinal flexing, and probable new faulting, as well as continued basin downwarping and movement on local folds. The northwesterly trends of many of the folds suggest renewed movement along lines of crustal weakness that were established by the end of late Paleozoic tectonism in the Colorado Plateau.

**Dating Late Cretaceous faults along west side Sawatch Range, Colo.**

The beginning of deformation along the margin of the Sawatch Range was bracketed by paleontological and radiometric age determinations. Fossils from the Mancos Shale collected by B. H. Bryant and identified by W. A. Cobban show that marine sedimentation in the Highland Peak quadrangle, Pitkin County, Colo. (loc. 12), continued near the site of the Sawatch Range at least into the *Exiteloceras jenneyi* zone. On the north flank of the San Juan Mountains, biotite and sanidine from tuff beds from this zone have been dated by K/Ar as 72.7 ± 2.2 and 75.2 ± 2.3 m.y. old, respectively (R. G. Dickenson, E. B. Leopold, and R. F. Marvin, r1320). In the Aspen quadrangle, muscovite from a quartz porphyry emplaced before major faulting along the margin of the Sawatch Range, has a K/Ar age of about 72.2 ± 2.2 m.y. In the Hayden Peak quadrangle, biotite contained in aplite whose emplacement seems fault controlled was dated by K/Ar as about 67.4 and about 70 m.y. old.

**Imbricate thrusts on west side of the Park Range, northern Colorado**

Imbricate thrusts that brought Precambrian crystalline rocks over Mesozoic rocks in northern Routt County, Colo. (loc. 13), were recognized by Kenneth Segerstrom and E. J. Young. These thrusts appear to be in the westward extension of a disturbed belt, characterized by multiple reverse faults, in northern North Park, Jackson County. Three major overthrusts striking north to northwest and dipping about 20° E. were mapped during 1968. Along the trace of each thrust, overturned beds of the Mancos, Cloverly, Morrison, and older formations are overlain by gneiss, schist, and granite referable to the Precambrian of the Park Range. The overthrust blocks and intervening sedimentary terrane are cut by east-west tear faults from 2 to 10 miles long. Some of the tear faults exhibit strong lateral displacement and extend farther west into Tertiary volcanic terrane.

**Quaternary faults in the Uinta Basin**

W. R. Hansen (r2124) reported that, although the Uinta Mountains region has been virtually aseismic in historic time, faulting was active during the late Pleistocene. South of the mountain front at Towanta Flat on the west side of the Lake Fork River, Utah (loc. 14), a graben and several subordinate fault scarps displace outwash terraces of probable Bull Lake age. Several of the fault scarps are more than 3 miles long, and one is about 40 feet high. Adjacent terraces and moraine of Pinedale age have not been affected.

**URANIUM IN COAL IN MADRID COAL FIELD, NEW MEXICO**

Local and sporadic occurrences of uranium in coal of Cretaceous age were discovered by G. O. Bachman in the Madrid coal field in Santa Fe County, N. Mex. (loc. 15). Concentrations of uranium in the ash range from 0.005 to 0.085 percent. Little is known about these occurrences to date, and additional study of them is warranted.

**BASIN AND RANGE REGION**

**Active uplift in San Simon Valley**

Currently active tectonic uplift in the San Simon Valley, southeastern Arizona (locality 1, index map) was recognized by G. P. Eaton in an analysis of repeated first-order leveling undertaken to study subsidence due to ground-water withdrawal. Two small areas of uplift, one in the center of the valley and the other closer to the margin, coincide with gravity and magnetic highs which can be ascribed to shallow bedrock horsts bounded by high-angle faults.

Topographic profiles across the central rise display local upward convexity, indicating that uplift has continued long enough and recently enough to affect the
gross form of the present topographic surface. Pronounced thinning of upper Pliocene or Pleistocene lacustrine sediments which extend across this feature suggests that the tectonic movement was initiated in, or prior to, Pleistocene time.

**Evolution of Tucson basin**

The deep central part of the Tucson basin, Arizona (loc. 2) has the form of a long narrow triangle and contains important supplies of ground water, according to E. S. Davidson. Its western boundary is a north-trending fault that extends from approximately Sahuarita to the junction of the Santa Cruz River and the Canada del Oro; on the northeast a west-northwest-trending fault follows approximately the coarse of Rillito and Tanque Verde Creeks; and on the east a poorly defined fault extends from about the mouth of Agua Caliente Wash southwest to Sahuarita. All the faults are buried by more recent alluvium, and in most places lie well out from the adjoining mountain fronts.

The basin was probably first blocked out in early Miocene time, after deposition of the Pantano Formation and Helmet Conglomerate, and apparently remained closed to exterior drainage through much of the Miocene and all of the Pliocene. The closure of the basin was accentuated by movement on northeast-trending faults near the end of Pliocene, but it remained closed until mid-Pleistocene, when the present through drainage was established, apparently as a result of regional tilting toward the northwest.

**Possible Navajo equivalent in western Nevada**

The youngest marine rocks in western Nevada are quartz sandstone of probable early Middle Jurassic age east of Lovelock in Pershing County (loc. 3), according to R. C. Speed. Eolian conditions are indicated by grain size and frosting. The sand probably migrated from a distant source, possibly the same one that gave rise to the Navajo Sandstone of Utah, and has been withheld from deposition by entrapment as beach deposits along a shoreline which migrated generally westward during early Mesozoic time. Deposition of the sandstone occurred chiefly in small downwarps created during the early stages of a major orogeny that affected western Nevada during the Jurassic.

**Southern limits of Roberts Mountains thrust**

Compilation of stratigraphic information from central Nevada by J. H. Stewart indicates that the Roberts Mountains thrust fault may not have extended south of about lat 38°50' N. North of this line, upper Paleozoic conglomeratic rocks overlie unconformably lower Paleozoic siliceous and volcanic rocks that characterize the upper plate of the Roberts Mountains thrust, whereas to the south such upper Paleozoic rocks rest unconformably on lower Paleozoic carbonate or transitional assemblage rocks that elsewhere make up the lower plate. The lack of upper-plate rocks south of about lat 38°50' N. suggests either that the thrust did not extend south of that latitude, or that upper-plate rocks were completely eroded prior to deposition of the upper Paleozoic conglomeratic strata.

**Tintic Valley thrust confirmed**

Exposures of the Tintic Valley thrust fault, long inferred in the subsurface of west-central Utah from closely adjacent outcrops of markedly dissimilar but correlative sequences of lower Paleozoic strata, were discovered in the Gilson Mountains (loc. 4) by H. T. Morris (U.S. Geological Survey) and Y. F. Wang (University of Utah). The fault crops out along the northeastern and southeastern margins of that range and has thrust Ordovician to Mississippian strata like those of eastern Nevada over predominantly clastic rocks of that Pennsylvanian and Permian Oquirrh basin. A structurally higher, subsidiary low-angle fault (the Champlin thrust) locally has placed younger on older strata within the Ordovician to Mississippian section of the Gilson Mountains.

Confirmation of the existence of the Tintic Valley thrust adds further support to the concept that imbricate thrust sheets of great extent moved eastward during late Mesozoic time along a belt that extended from Montana to southeastern Nevada.
GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE STUDIES

PACIFIC COAST REGION

Western extension of Arizona Paleozoic section in southeastern California

W. B. Hamilton reported that metamorphic equivalents of Paleozoic strata of the stable platform facies which occur in the Grand Canyon region are present in the region of Mesozoic metamorphism and granitic batholiths in eastern Riverside County, Calif. (locality 1, index map). Geologic mapping in the Big Maria, Little Maria, and Riverside Mountains has shown that in order upwards from the polymetamorphic Precambrian plutonic basement complex, and as dated by stratigraphic sequence and lithology, the Paleozoic succession consists of Cambrian quartzite (Tapeats) and schist (Bright Angel), undated calcite marble and dolomite marble that thicken northwestward, Mississippian calcite marble (Redwall), and Permian impure quartzite (Supai), schist (Hermit), pure quartzite (Coconino), and calcite marble (Kaibab). Metamorphism of the strata to greenschist and amphibolite facies mineral assemblages was accompanied by intense deformation. Maximum present thickness of the entire Paleozoic section is about 1 mile, which presumably approximates the initial sedimentary thickness; maximum tectonic thinning reduces the entire section to as little as 30 feet thick, all formations being present. Several tens of thousands of feet of Mesozoic clastic and volcanic rocks overlie the Paleozoic section and with it have been metamorphosed and intruded by granitic plutons. The Paleozoic rocks occur in isoclinal synclines enclosed in basement rocks, and in thrust complexes caught between sheets of basement rocks.

Southern Klamath Mountains

W. P. Irwin, mapping in the Hayfork and Dubackella Mountain quadrangles, southern Klamath Mountains, Calif. (loc. 2), recognized that the western Triassic and Paleozoic belt consists of two terranes that are separated by a northwest-trending fault of regional extent. The western of these two terranes includes abundant serpentinite and unusual albitic granitic rocks; the eastern terrane includes a distinctive, thick, augite andesite volcanic formation. Significant gold deposits, both lodes and placers, are virtually restricted to the eastern terrane. In this part of the Klamath Mountains the gold deposits are distributed along the boundary between the augite andesite formation and other rocks of the eastern terrane. The cause of the apparent localization of lode gold deposits along this boundary is not known.

Studies of Sierra Nevada roof pendants

A small roof pendant of metasedimentary rocks and metamorphosed shallow intrusives which is surrounded by Mesozoic granitic rocks is the locus for tungsten deposits at the Strawberry mine, southeast Merced Peak quadrangle, California, in the Sierra Nevada (loc. 3). Warren Nokleberg, who has been making a geochemical study of the tungsten deposits, reported that marble beds in the pendant are metasomatized to andradite-hedenbergite-scheelite tactite by volatile-rich fluids containing silicon, iron and tungsten which were expelled from a granodiorite magma. The geochemical study indicates that the various contact metamorphic assemblages and their oxidation states can be explained by a simple model that considers interaction of the ore solutions with large amounts of carbon dioxide during replacement of the marble. Detailed mapping and structural analysis of minor folds in the pendant show that the rocks underwent four periods of deformation before intrusion of the granitic magmas. The pattern of superimposed folds is regional in extent and can be correlated with folds in other pendants in the Sierra Nevada.
Studies by R. S. Fiske of Triassic (?) and Jurassic metavolcanic rocks in the Ritter Range pendant, Devils Postpile quadrangle California (loc. 4), indicate that the material deposited in the thick pre-Sierra Nevada geosyncline consists of about 95 percent pyroclastic debris, 5 percent lava flows, and less than 1 percent carbonate rock. Many shallow water and subaerial sedimentary structures have been recognized in the rocks, which suggest that the rate of subsidence of the geosyncline very nearly kept pace with the volcanic sedimentation as the reginal downwarping proceeded.

Cenozoic stratigraphy and structure in coastal California

Detailed geologic mapping by R. H. Campbell and R. F. Yerkes in the north part of the Malibu Beach quadrangle, central Santa Monica Mountains (loc. 5), supported by many fossil identifications by W. O. Addicott, led to the recognition that the so-called Upper Topanga Formation of Durrell 36 includes middle Miocene breccia and conglomerate that contains clasts of fossiliferous Paleocene and Eocene sandstone. One conspicuous bed of this sort of breccia, as much as 260 feet thick, provides a useful local marker horizon that can be followed for several miles. In addition, smaller, discontinuous lenses of breccia occur at different horizons and, in a few places, isolated fossiliferous boulders and cobbles are present in otherwise unfossiliferous conglomerate lenses. Indigenous middle Miocene mollusca are rare, but in at least one area a mixed fauna is obtained where sandstone boulders containing early Tertiary faunas are associated with indigenous middle Miocene mollusca. Clasts probably derived from the Sespe Formation or from fossiliferous lower or middle Miocene rocks, such as those that predominate in the sedimentary breccia noted in “Upper Topanga” beds of the Malibu Bowl thrust sheet to the southwest, have not been found in the breccia beds of this area.

J. C. Clark discovered stratigraphic relations which indicate that the San Gregorio fault, a major structure in the western Santa Cruz Mountains, San Mateo County (loc. 6), has had significant vertical and (or) lateral displacement during Cenozoic time. The fault trends northwestward from Ano Nuevo Bay to San Gregorio, a distance of approximately 20 miles. West of the San Gregorio fault, basement rocks are not exposed, and the oldest sedimentary section consists of more than 8,500 feet of sandstone and conglomerate of Late Cretaceous age. To the east of this fault and west of the San Andreas fault, Cretaceous sedimentary rocks are absent, and the oldest sedimentary rocks are of Paleocene age and rest upon a granitic basement.

Recent mapping has also revealed significant differences in the Miocene sedimentary sections that are juxtaposed along the San Gregorio fault. A middle Miocene section west of the fault is faunally and lithologically different from the correlative section to the east. A several-thousand-foot-thick mudstone section of late Miocene age to the east of the fault is represented by an unconformity to the west.

Cenozoic paleoclimates in the Pacific coastal area

W. O. Addicott deduced the marine climates prevailing during the Cenozoic in the Pacific coastal area from paleontologic studies of molluscan faunas. Usually large percentages of warm water molluscan genera are found in the Eocene and Miocene faunas of the northeastern Pacific Ocean, reflecting successive episodes of marine climate substantially warmer than at present. A new analysis of faunas from rather complete depositional sequences in central California showed an increase in the proportion of warm water genera from a middle Oligocene low to a middle Miocene peak. After the middle Miocene peak, a climatic reversal set in, as indicated by the disappearance of tropical molluscan genera from central California faunas by the end of the Miocene, and the last appearance of subtropical genera in the Pliocene.

Stratigraphic and structural studies in coastal Oregon and Washington

R. G. Coleman’s studies in the Agness, Collier Butte, Gold Beach, and Port Orford quadrangles (loc. 7) helped to explain some of the puzzling structural and stratigraphic problems in southwest Oregon. Cretaceous thrusting on serpentinite “tectonic crat-cts” has placed Colebrooke Schist on top of eugeosynclinal and miogosynclinal sedimentary rocks that range in age from Late Jurassic (Dothan and Galice Formations) to Early Cretaceous (Myrtle Group). Eocene conglomerates (Umpqua Formation), containing both Colebrook Schist and serpentinite clasts, rest unconformably on the Colebrook Schist and its thrust cont-cts with the underlying Mesozoic sedimentary rocks.

The Colebrook Schist is composed predominantly of fine-grained sedimentary rocks and pillow lavas which have been metamorphosed under conditions intermediate between the blueschist and greenschist facies. Two periods of deformation can be recognized in the Colebrooke Schist: the first related to metamorphic recrystallization, the second to eastward thrusting. Bulk chemistry and isotopic data suggest that pelitic schists of the Colebrookes were originally deep ocean sediments that contained a high content of oceanic vol-
cogenic material, and only a small amount of detritus derived from significantly older crust. Associated pillow lavas have low initial Sr/Sm (0.704) and K (1,108 ppm), which indicate that they are oceanic tholeiites.

Crustal shortening related to ocean floor spreading may have been responsible for the present allochthonous position of the Colebrooke Schist.

Reconnaissance mapping by P. D. Snavely, Jr., N. S. MacLeod, and W. W. Rau of parts of six quadrangles in the Tillamook highlands area of the northern Oregon Coast Range (loc. 8) led to a reinterpretation of the age of the Tillamook Volcanic Series, previously regarded as middle Eocene. The Tillamook Volcanic Series occupies a large north-plunging anticlinorium complicated by northwest- and northeast-trending faults. These rocks can be divided into three mappable units. The lower unit, whose base is concealed, consists of basaltic pillow lavas, tuffs and breccia and interbedded siltstone and sandstone from which Foraminifera of early to middle Eocene age have been identified. This lower unit is correlative with the Siletz River Volcanics of the central Oregon Coast Range.

The middle unit, which probably is correlative with the Yamhill and Tyee Formations and uppermost part of the Siletz River Volcanics, is approximately 2,500 feet thick and composed of tuffaceous siltstone, arkosic sandstone, organic shale, and basaltic tuff, breccia and pillow lavas. Preliminary paleontologic studies indicate that the middle unit ranges in age from middle to early late Eocene. The uppermost unit consists of more than 5,000 feet of subaerial basalt flows, which are correlated with volcanic sequences on the central Oregon coast that are included with the Nestucca Formation (late Eocene). The upper unit is overlain by early Oligocene (?) tuffaceous siltstone and basaltic conglomerate and sandstone.

Mapping by R. W. Tabor and R. S. Yeats in the Mount Angeles quadrangle, Olympic Mountains, Wash. (loc. 9) showed that Eocene sedimentary rocks and associated submarine volcanic rocks are arranged in three concentric belts concave to the southwest toward the core of the range. The volcanic rocks are thickest in the outermost belt where they are called the Crescent Formation; they become thinner and more discontinuous in each succeeding belt southwest. Microfossils studied by W. W. Rau indicated that volcanic rocks of the innermost belt are the same age as those in the outermost belt and thus probably represent the distal edge of a large volcanic pile. The structure of the belts becomes more complex towards the southwest, and the sedimentary rocks grade irregularly from argillite to phyllitic schist. The three belts are separated from one another by thrust faults along which the pre-dominantly volcanic Crescent Formation and younger rocks were thrust westward or southwestward over the thinner, seaward margins of the volcanic pile. Later doming of the Olympic Mountains caused steepening and overturning of the beds and fault zones, and produced the concentric pattern seen today.

**Discovery of magnesite in Okanogan County, Wash.**

Geologic mapping in northern Okanogan County, Wash. (loc. 10) by K. F. Fox, Jr., and C. D. Rinehart revealed a persistent belt of discontinuous exposures of magnesite and magnesite-bearing dolomite. The belt is about 50 miles long, extending from near Riverside northward to Oroville and thence eastward to a few miles beyond Chelan. The magnesite zone is typically no more than 50 feet thick, but preliminary work indicates that magnesite in some deposits in the northern part of the belt may be of mineable grade and size. The zone occurs along an unconformity at the base of a sequence consisting mostly of unfossiliferous greenstone and metachert, but locally consisting of limestone and dolomite which contain fossils of Triassic age. Cause of its persistence over long distances, the magnesite zone is a valuable regional stratigraphic marker. A more complete description of the magnesite deposits is given by Fox and Rinehart (r0226) elsewhere.

**Ultramafic rocks in California and Washington**

Detailed structural and petrologic examination of a peridotite body at Burro Mountain, Calif. (loc. 11), was completed by R. A. Loney, G. R. Himmelberg, and R. G. Coleman as part of a continuing integrated study of alpine-type ultramafic rocks in the Coast Ranges. These investigators concluded that the Burro Mountain peridotite mass originated from an ultramafic magma that probably crystallized in the mantle. The peridotite was subsequently emplaced, as a plug-like cold intrusion into a structurally chaotic terrane composed of rocks of the Franciscan Formation which had been regionally metamorphosed to mineral assemblages characteristic of the pumpellyte-meatagryite facies. Deep-seated plastic deformation of the peridotite involving intergranular gliding and recrystallization resulted in formation of a metamorphic foliation and development of isoclinal folds. Tectonic fracturing, which took place at relatively shallow depths, provided channels for the access of serpentinizing waters into the peridotite. A radial fault pattern in the plug-like ultramafic body suggests circumferential expansion of the mass either by release of pressure, serpentinization, or both.

The first occurrence of ultramafic rock in the Olympic Peninsula, Wash., was reported by W. M. Cady
and M. S. Miller from an area 2 miles west of the northwest end of Lake Cushman, in the southeastern Olympic Peninsula (loc. 12). The rock is serpentinized feldspathic peridotite and is accompanied by hornblende gabbro and diabase. Small intrusive bodies of the ultramafic and mafic rocks intrude a 2-mile-thick section of Paleocene to lower Eocene marine sedimentary rocks that underlie oceanic tholeiitic pillow basalts in the lower two-thirds of the Crescent Formation (Eocene).

Geochronology

Plutons in the northern part of the Klamath Mountains were dated by K-Ar age determinations made on hornblende and biotite from 13 samples of plutonic rock collected by P. E. Hotz in southwestern Oregon (loc. 13), according to M. A. Lanphere. The rock samples range in composition from gabbro to quartz monzonite. A group of ages that lies between 134 and 151 m.y. was obtained from 16 mineral concentrations from 12 of the samples. One other sample yielded discordant ages of 145 and 160 m.y. on biotite and hornblende, respectively. The ages obtained are similar to those previously determined for plutons in the central and southern Klamath Mountains, Calif., but cannot be resolved into several groups as was done in the southern part of the province (M. A. Lanphere, W. P. Irwin, and P. C. Hotz, r1021).

J. C. Engels and D. F. Crowder reported that K-Ar ages determined on biotite-hornblende pairs from samples of granitic rock from the Mount Stuart batholith, Chelan County, central Washington (loc. 14), indicate a minimum age of 90 m.y. for the pluton. Slightly younger ages for the northern part of the batholith are indicated by K-Ar determinations on biotite and fission-track data on apatite. The younger ages possibly indicate reheating by later intrusions.

Regional geophysics in California

The U.S. Geological Survey in cooperation with the California Division of Mines and Geology and the U.S. Army Map Service is making a 5-mgal Bouguer gravity map of the entire State of California at a scale of 1:250,000 to be completed by 1970. Gravity observations are being made along roads at 3-5-km intervals and between roads with a maximum spacing of 8 km. All the data are being terrain-corrected by new computer methods. Local calibration loops have been established between Menlo Park and Mount Hamilton (310 mgal), Merced and Sentinel Dome (620 mgal), and Bakersfield and Mount Pinos (595 mgal) to refine factory calibrations as well as to test new instruments for drift characteristics and reproducibility under field conditions.

H. W. Oliver reported that new data in the northern Sierra Nevada indicate that the major gravity low previously reported over the southern Sierra extends throughout the length of the range, gradually decreasing to the north in general accordance with isostasy. Oliver also reported that a preliminary study of the quantitative relationship between gravity and topography along several east-west profiles across California suggests that Bouguer anomalies (BA) at bedrock stations may be approximated by the linear relationship

\[ \text{BA} = -0.0965 \times 64 \pm 8 \text{ mgal} \]

where \( E_0 \) is the elevation in meters surrounding the gravity station averaged to a radius of 64 km.

An aeromagnetic survey interpreted by Andrew Griscom showed that the Salton Sea geothermal area (loc. 15) is underlain by a large anomaly elongate in a northwest-southeast direction. Two magnetic peaks of smaller areal extent are superimposed on the larger anomaly at its southern end. Griscom's analysis of the data suggests that the large anomaly is caused by a tabular pluton at least 12 miles long, 4 miles wide, and approximately 10,000 feet thick, which is about 10,000 feet below the surface. A group of small, near-surface dikes and sills are believed to be responsible for the two smaller areas of high magnetic intensity. The active steam wells of the Salton Sea geothermal area are located on the southernmost of the two subsidiary anomalies. The other, similar anomaly, 4 miles to the northwest, appears to be an additional favorable area to explore for geothermal energy.

ALASKA

Significant new scientific and economic results of geological field studies and of related geophysical, paleontological, geochemical, and petrologic investigations in Alaska this past fiscal year are here summarized. For easy reference the discussion is divided into six parts corresponding to six major regions - and the locations of the regions and specific study areas are shown on the accompanying index map of Alaska.

NORTHERN ALASKA

Romanzof Mountains, northeastern Brooks Range

Brief regional and topical studies of rocks along the north edge of the eastern Brooks Range in 1968 by H. N. Reiser and I. L. Taillleur (locality 1, index map), in conjunction with the investigation of the organic shales in northern Alaska, gained special importance because of the concurrent discovery of large oil reserves in the subsurface projection of these rocks. This new information, together with earlier photogeologic and field studies of the outcrop region close to the
newly discovered oil fields, and available data from oil companies was compiled in a recently released preliminary geologic map of the Mount Michelson 1 200,000-scale quadrangle by H. N. Reiser and I. L. Tailleur (19094). Significant new observations and interpretations in the northeastern Brooks Range are summarized in the following paragraphs.

Thick sections of carbonate rocks of the Lisburne Group underlain discordantly by a unit of dolomite and limestone occur in the Sadlerochit Mountains and Shublik Mountains anticlinoriums. The lower unit is Middle Devonian or older as determined from corals in its upper part identified by W. A. Oliver, Jr., and is at least in part referable to the Baird Group.

A. K. Armstrong reported that the Lisburne Group in the Franklin Mountain anticlinorium consists of more than 2,000 feet of largely open marine Upper Mississippian and younger limestone, but in the Sadlerochit anticlinorium nearly 20 miles to the north the Lisburne consists of about 1,500 feet of more restricted marine, later Upper Mississippian and younger limestone. The change to clastic rocks of the overlying Sadlerochit Formation is locally rapid but gradational, and the transitional strata contain brachiopods identified as middle Permian by J. T. Dutro, Jr. The Sadlerochit does not appear to be more than 1,000 feet thick in the outlying ranges and probably is thinner to the east.

The upper 500 feet of the Sadlerochit at the east end of the Shublik Mountains anticlinorium typifies the unit and was studied by H. A. Tourtelot. The Sadlerochit consists of about 50 percent siltstone, 25 percent shale, and 25 percent nearshore-facies sandstone and quartz-chert conglomerate. The overlying Shublik Formation consists of 400 feet of phosphate-nodule-bearing black shale or mudstone, black fossiliferous limestone, and dark silty carbonate or siltstone.

Several fossil collections made from the Shublik Formation on the east nose of the Shublik Mountains anticlinorium during the study by Tourtelot indicated that the unit is Middle Triassic (Ladinian) to latest Triassic according to N. J. Silberling. Sixty miles to the east, on the Aichilik River, the Shublik Formation is 700 feet thick and contains coarser terrigenous mate-
About 150 feet of Jurassic (?) clastic rocks overlie the Shublik where it is latest Triassic in age.

Rocks typical of the Kingak Shale are reported to extend into the Lower Cretaceous (Neocomian). Sandstone and pebble conglomerate mapped previously as the Albian age lower member of the Ignek Formation seem to be the northeastward projection of the Kemik Sandstone Member of the Okpikruak Formation (Neocomian). The Kingak Shale is in most places less than the 4,000 feet reported on the Canning River. A post-Neocomian unconformity is suggested by the presence of organic shale, like that in the Colville Group (Upper Jurassic), and volcanogenic (?) beds locally overlying older shale.

The northeastern Brooks Range is structurally simpler than the rest of the deformed belt, in that large-scale thrusts appear to be lacking. However, large dislocations within the mountains cannot be ruled out without further study of the contrasting facies of the Lisburne Group and Shublik Formation that occur within the area. The pre-Mississippian unconformity, which was originally planar, is folded smoothly and broadly and is a décollement surface along which the overlying Mississippian through Cretaceous beds have been strongly crumpled and foreshortened.

Field evidence suggests a Cretaceous age of emplacement for the Romanzof pluton rather than the Devonian age obtained earlier by radiometric methods.

Late Paleozoic deformation and granitic intrusion in the eastern Brooks Range

W. P. Brosge and H. N. Reiser reported that a belt of pre-Mississippian folding and metamorphism, previously known only in the northeastern part of the Brooks Range, seems to extend south (loc. 2) through the Davidson Mountains almost to the Porcupine River. In both areas, Upper Mississippian limestone of the Lisburne Group is underlain by a thin conglomerate that rests unconformably on schist, and in both areas the schist has been intruded by granite. The age of the granite in the northeast Brooks Range is still unknown, but radiometric age determinations by J. C. Von Essen indicated a Carboniferous age for the granite in the Colleen quadrangle near the Porcupine River and suggested further that the granite cooled in the interval represented by the Lower Mississippian hiatus in the sedimentary section.

WEST-CENTRAL ALASKA

Paleozoic and Mesozoic sequence mapped on St. Lawrence Island

Mapping by W. W. Patton, Jr., J. T. Dutro, Jr., (p. D138-D143) and Bela Cæjetey, Jr., documented the presence on St. Lawrence Island (loc. 3) of a here-tofore little known Paleozoic and Mesozoic sequence possibly as much as 8,000 feet thick. The oldest strata are represented by a thick unit of Devonian dolomite and dolomitic limestone. This unit appears to be succeeded unconformably by at least 1,000 feet of Upper Mississippian limestone and cherty limestone. The rocks are in turn overlain unconformably by a 400-foot shaly unit that is probably of Early Triassic or Permian age in the lower part and is definitely of Middle and Late Triassic age in the upper part. The youngest sedimentary rocks are graywacke and mudstone tentatively assigned a Jurassic or Cretaceous age.

Equivalent similar rocks having similar fossils occur in the western and central Brooks Range, and counterparts of some of them appear to be present on the Seward and Chukotsky Peninsulas.

Thrust faulting on Seward Peninsula, Alaska

Continued mapping of the Seward Peninsula at a scale of 1:250,000 has demonstrated that rocks of the entire Seward Peninsula are involved in thrust sheets of a major thrust belt that C. L. Sainsbury and Reuben Kachadoorian propose to name the Collier thrust belt in honor of A. J. Collier, pioneer geologist on the Seward Peninsula. A large terrane of blueschist facies rocks was defined. The Paleozoic rocks, almost entirely carbonates from the pre-Ordovician through at least the Mississippian, reflect shelf-type sedimentation. In the western Seward Peninsula, thrust sheets of unmetamorphosed carbonate rocks lie above high-rank metamorphic rocks; at the east end of the peninsula, the Paleozoic carbonate rocks are metamorphosed to marble, but rest upon metamorphic rocks of much higher rank.

A regional zonation of mineral deposits is suggested, from greisen-type tin deposits on the western Seward Peninsula to base-metal deposits with silver and moderate amounts of tin in the central and eastern Seward Peninsula.

EAST-CENTRAL ALASKA

Little-known ultramafic belt mapped in Bettles-Tanana quadrangle

Reconnaissance mapping in the Bettles and Tanana quadrangles of (loc. 4) of central Alaska by W. W. Patton, Jr., T. P. Miller, and R. L. Elliott revealed the presence of a number of little-known and here-tofore unmapped ultramafic bodies along the southeast flank of the Yukon-Koyukuk basin. These include six large masses 2 to 17 miles long and half a mile to 3 miles wide as well as numerous smaller masses. The ultramafic bodies are distributed along a linear belt of altered pil-
low basalts, diabases, and cherts of probable Jurassic age, flanked on the northwest by sedimentary and volcanic rocks of the Yukon-Koyukuk Cretaceous basin and on the southeast by Paleozoic and Precambrian metamorphic rocks of the Kokrines-Hodzana highlands. The alignment of these ultramafics along the margin of the basin and their close spatial relationship with the volcanics and cherts suggests that they may represent part of an ophiolite assemblage emplaced during the initial phases of the formation of the Yukon-Koyukuk basin.

Anomalous gold concentrations found in fracture and shear zone in Fairbanks district

In completing the 1/24,000-scale geologic map of the Fairbanks district (loc. 5) and accompanying geochemical and geophysical investigations, R. B. Forbes, H. D. Pilkington, and D. B. Hawkins located several anomalous gold concentrations in addition to those found in 1967. Gold anomalies were found in fracture and shear zones as much as 40 feet wide, in quartz monzonite, quartz diorite, and crystalline schists. Most of these anomalies are surrounded by halos containing trace antimony, arsenic, or both. Sampling of discordant quartz veins beyond the usual limits of the Fairbanks lode belt showed that the zone of trace gold enrichment is much broader than previously recognized.

Geochemical sampling on the southeast slopes of Ester dome confirmed several wide hydrothermal alteration zones in crystalline schists. These zones contain anomalous amounts of gold, and at least one high-grade gold-quartz vein was found.

Geochemical and structural data gathered by Forbes, Pilkington, Hawkins, and R. M. Chapman show that fracture zones and shear zones along the axial zone of the Cleary anticline cut all of the major rock units, and that heavy-metals mineralization is accompanied by silicification and hydrothermal alteration along these zones. Some of the more persistent zones in the quartz diorite and crystalline schists may be of potential economic interest.

Mineral occurrence in eastern Alaska Range described

Geochemical investigations by D. H. Richter and N. A. Matson, Jr., in the Slana area of the eastern Alaska Range (loc. 6), in cooperation with the Alaska Division of Mines and Geology, suggest that lead-zinc-molybdenum-silver mineralization is associated with a large zoned quartz monzonite-granodiorite pluton, whereas gold-copper mineralization is associated with small diorite-quartz diorite intrusives. Around the periphery of the quartz monzonite-granodiorite pluton quartz veins carrying lead, zinc, and silver are known, and at least two large and possibly significant lead, zinc, and molybdenum anomalies were delineated by stream-sediment sampling. Anomalous gold values (as high as 7 ppm) appear to be restricted to streams draining areas underlain by diorite or quartz diorite. The distribution of gold in bedrock also follows the pattern shown by the stream sediment data. Samples of diorite contain as much as 0.8 ppm Au; quartz monzonite and granodiorite samples from the pluton were not found that contain more than 0.02 ppm Au, the lower limit of detection.

Richter and Matson also reported that a thick unit of amygdaloidal basalt flows of Permian or Triassic age in the eastern Alaska Range warrants attention as a potential source of copper. The unit, which is about 5,000 feet thick, has now been traced from the head of the Chistochina River in the Mount Hayes quadrangle, southeast over 140 miles to the Canadian border. Native copper and some copper sulfides occur in minor amounts throughout the flows in amygdules, scoriaceous flow tops and bottoms, and in fractures and local shear zones. Mineralogically and petrographically the flows appear similar to the Precambrian basalts of the upper peninsula of Michigan and the Nikolai Greenstone of Triassic age exposed along the south flank of the Wrangell Mountains in Alaska. Amygdule minerals consist chiefly of chlorite, calcite, quartz, and epidote with lesser amounts of pumpellyite, prehnite, hulandite, analcime and natrolite.

Structural and stratigraphic relationships in the White Mountains reexamined

Structural and stratigraphic relations in the White Mountains (loc. 7), delimited by R. M. Chapman, Michael Churkin, Jr., Donald Grybeck, and P. R. Welsh, resolve conflicting interpretations of previous workers. The prominently outcropping limestones and dolomites of the Tolovana Limestone (Silurian and (or) Devonian) are in conformable sequence with both underlying and overlying units. The underlying unit is a thick succession of volcanic and volcaniclastic rocks, graywacke, and calcareous argillite whose age span is unknown; the overlying rocks are upper Middle or lower Upper Devonian clastics. The entire sequence has been tightly folded, but thrust faults probably form the northern and southern boundaries of the sequence.

Serpentinized ultramafic rocks discovered in Eagle region

H. L. Foster (r0791) discovered numerous small serpentinized ultramafic bodies in the Eagle region (loc. 8) during reconnaissance geologic mapping. They are most abundant in areas of green schist facies metamorphic rocks and rare in amphibolite facies metamorphic rocks.
One exposure in the Eagle C-4 quadrangle consists of large joint blocks of serpentine cut by closely spaced veins, about one-fourth inch thick, of cross-fiber chrysotile asbestos. The asbestos appear to be of commercial quality, but the quantity is unknown.

The dominant structural feature of the region is the Tintina fault zone, and some of the ultramafic rocks appear to align with northwest-trending linear zones parallel to the Tintina trend. Other exposures appear to be randomly distributed.

**SOUTHWESTERN ALASKA**

**History of volcanism on Nunivak Island**

J. M. Hoare and W. H. Condon reported that volcanic activity apparently began on Nunivak Island (loc. 9) about 6 m.y. ago with the eruption of inclusion-bearing alkalic basalts. Volcanic activity continued as a series of pulses up to near-present time. Several of the pulses included both tholeiitic and alkalic basalt. The stratigraphic relations of the basalts suggest that alkalic eruptions generally precede tholeiitic eruptions.

The youngest of tholeiitic eruptions began about 0.9 m.y. ago, and continued until 0.2 m.y. ago. At Roberts Mountain these young tholeiitic flows are underlain and overlain by inclusion-bearing alkalic basalts. The older alkalic basalts are interpreted as forerunners of the overlying tholeiites. The overlying alkalic basalts which erupted after an erosion interval of about 0.2 m.y. are interpreted as the beginning of a new pulse of volcanism.

Similar volcanic sequences elsewhere in the Bering Sea volcanic province suggest a similar interpretation. In two other volcanic centers the latest volcanic pulse appears to have progressed to the tholeiitic stage of eruptions.

**Presence of Paleozoic rocks in Aleutian Island chain disproved**

Supposed upper Paleozoic rocks on Adak Island (loc. 10) were shown to be of early Tertiary age. An outcrop of the Finger Bay Volcanics on Adak Island had yielded fossils resembling *Annularia stellata*, a land plant hitherto considered to have become extinct at the end of Paleozoic time. However, the matrix of the *Annularia*-bearing beds contains dinoflagellates indicative of an early Tertiary age; beds on strike with the outcrop contain fish of a group not known in pre-Tertiary rocks; and beds a few hundred meters stratigraphically higher in a conformable sequence contain early Tertiary mollusks and Foraminifera. D. W. Scholl concluded that this discovery removes the most important obstacle to the hypothesis that the Aleutian Ridge originated early in Tertiary time. (A more detailed description of the fossils mentioned above is given on p. A135.)

**SOUTHERN ALASKA**

**Gold veins in Nuka Bay**

Field studies by D. H. Richter in the Nuka Fay area (loc. 11) on the Kenai Peninsula have established that folded slate and graywacke of Cretaceous age and minor dioritic dikes and sills are host rocks for a number of gold-bearing quartz veins. The veins are generally short, thin, and discontinuous but locally certain as much as 9 oz Au per ton in zones as much as 2 feet wide. The larger and more mineralized veins appear to be restricted to massive, competent graywacke beds or to some brittle dikes where they fill tensional cross joints formed as a result of the orogenic folding. The area produced some gold during 1924-1940 but since then has been relatively inactive. Alkali granite veins are thin and gold values are erratic, the high tenor and relative ease of extracting the free-milling gold indicate that diligent small-scale mining may be economically feasible.

**Carbonate lithofacies in Kennecott district may be related to ore deposition**

Carbonate petrographic studies by A. K. Armstrong (p. D49-D62) led to the conclusion that much of the lower strata of the Chitistone Limestone in the Kennecott district (loc. 12) formed in intertidal and supratidal environments and that much of the formation's dolomite is primary or early diagenetic in origin. Such environments are favorable for the formation of saline brines, and it is inferred that thermal brines were important in the genesis of the Kennecott copper lodes that are localized in beds near the base of the Chitistone Limestone. Such brines could have been heated and mobilized during the Tertiary plutonism and volcanism that affected the region, acquiring their copper while migrating through the underlying Nicolai Greenstone, and subsequently deposited their metals at favorable structural sites in the Chitistone Limestone.

**Mapping in Yakutat region documents widespread tectonic breccia**

Geologic mapping by George Plafker and M. S. Perkins in outcrop areas of Mesozoic eugeosynclinal rocks (the Yakutat Group and an unnamed “volcanic unit”) in the Yakutat District (loc. 13) demonstrated that these rocks are, to a large extent, tectonic breccias or melanges. Both units are characterized by the occurrence of tectonically mixed fragments or blocks of competent rocks, as much as several miles long, in a perva-
sively sheared matrix of pelite or tuffaceous pelite. The blocks include disrupted beds of wacke sandstone and conglomerate that were originally interbedded with the siltstone as well as “exotic” greenstone, marble, diorite, volcanic graywacke, chert, and oolitic limestone of widely diverse origins and ages. Rocks previously differentiated as the “volcanic unit” along Russell Fiord and on the Yakutat foreland appear to be portions of the melange with especially abundant greenstone exotics. Recognition of the Yakutat Group and “volcanic unit” as tectonic breccias, rather than rock-stratigraphic sequences, helps resolve many of the puzzling stratigraphic and structural relationships in the outcrop and in exploratory oil wells that penetrated these units on the Yakutat foreland.

Layered ultramafic rocks discovered on Mount Fairweather

During the course of a geochemical sampling program in the Yakutat quadrangle and adjacent areas (loc. 14), George Plafker and E. M. MacKevett, Jr., traced float mafic and ultramafic rocks in glacial moraines to a pluton on the southwest flank of Mount Fairweather. The outcrop could not be reached because of rugged terrain, but aerial observation indicated that the float rock was derived from a stratiform pluton which is exposed above an altitude of about 8,000 feet over an area of several square miles. The discovery is noteworthy because it extends the known occurrence of mafic and ultramafic rocks in the Fairweather Range 20 miles farther northwest and because nickel-copper deposits of potential economic importance are known to be associated with bodies of ultramafic rock elsewhere in the Range.

SOUTHEEN ALASKA

Igneous events dated in Glacier Bay region

At least three, and probably four, distinct igneous events, were recognized in Glacier Bay National Monument, Alaska (loc. 15) on the basis of field studies by D. A. Brew, J. G. Smith, and others and on potassium-argon dating of critical specimens by M. A. Lanphere. The oldest event occurred about 110 m.y. ago and involved the emplacement of well-foliated tonalite and granodiorite nearly parallel to the regional structural trends. About 30 m.y. ago internally foliated granodiorites were intruded both across and parallel to the regional trends. They were followed by discordant, unfoliated, leucocratic adamellite and granodiorite about 31 m.y. ago. The large layered gabbro complexes of the Fairweather Range were intruded in Cretaceous or Tertiary time. This event is not yet dated by direct methods.

Cretaceous age established for major rock unit in Juneau area

Field studies by D. A. Brew, A. B. Ford, and J. G. Smith on Douglas Island near Juneau (loc. 16) revealed unsuspected structural complications and provided a significant fossil collection. As recognized in the old reports, the phyllite, black slate, graywacke, and interlayered greenstone typical of the Treadwell mine area extend northward to the end of the island. Poorly understood large structures or facies changes are indicated by the way this unit appears to wrap around the “augite melaphyre” which underlies most of the high part of the island. The significant fossil collection came from the broad transition unit between the melaphyre unit and the phyllite, slate, and graywacke unit; the collection is of _Inoceramus_ of probable Late Cretaceous age. This is the only fossil collection of this age in southeastern Alaska, and it suggests that much of the graywacke and greenstone mapped as Late Jurassic and Early Cretaceous along the southwest flank of the Coast Range composite batholith may be Late Cretaceous instead.

Gastineau Channel fault not of major tectonic significance

On the basis of recent studies near Juneau, D. A. Brew and A. B. Ford concluded that the controversial Gastineau Channel fault (loc. 17) exists but that it is not of major tectonic significance. The fault occupies a critical position between Douglas Island and the mainland in the Juneau gold mining district, and its movement history bears on several stratigraphic and mineral deposit problems. Evidence for the fault is: (1) contrasting structural domains along part of its length, (2) a 20-degree angle between its trace and the strike of the mainland bedrock, (3) submarine scarps in the channel, (4) extensive fracturing along the trace about 8 miles northwest of where the fault leaves the channel for the mainland, and (5) probable difference in age of rocks on either side of the channel at Juneau. Other evidence suggests that the amount of movement is small: (1) metamorphic grade is the same on both sides, (2) mainland exposures close to where the fault leaves the channel show little structural discordance or anomalous fracturing, and (3) the Silverbow fault which intersects the Gastineau Channel fault at a high angle at Juneau, appears to be separated left laterally less than half a mile.

Possible 120-mile displacement along Chatham Strait fault

Investigations of Paleozoic rocks east and west of the Chatham Strait fault (loc. 18) in southern and northern southeastern Alaska by A. T. Ovenshine, G.
D. Webster, J. G. Evans, and A. G. Barrows yielded new data bearing on the nature and amount of displacement on this major strike-slip fault. Reconnaissance mapping of Coronation and southern Kuiu Islands, on the east side of the Chatham Strait fault, has defined a distinctive unit of limestone and rhyolite conglomerate and penecontemporaneously deformed argillite containing limestone blocks up to 150 feet long. On the west side of the fault, metamorphosed counterparts occur in the vicinity of Basket Bay on Chichagof Island, approximately 120 miles north of the Kuiu-Coronation area. This distinctive unit is the first identified on both sides of the fault, and the distance apart of the two areas is a measure of the separation of the fault. The “wildflysch” nature of the formation, as well as its location along a major regional facies boundary, indicates that it is a slope deposit of limited extent. Hence in the analysis of fault movements, it may be treated as a line intersecting the fault surface at a point. Right-lateral displacement of 120 miles is therefore indicated for the Chatham Strait fault.

Geologic mapping on Annette Island completed

Completion of mile-to-inch mapping of Annette Island (loc. 19) by H. C. Berg showed that its rocks can be divided into 3 distinct groups: the Annette pluton, metamorphic and igneous rocks older than the Annette pluton, and sedimentary and igneous rocks that postdate the pluton. The oldest dated preplutonic rocks consist of fossiliferous Devonian limestone and phyllite; younger preplutonic rocks are recrystallized (greenschist facies) sediments and volcanics, and foliated quartz diorite. The preplutonic sequence is cut by the Annette pluton, a 150-sq-mi syntectonic (?) batholith consisting mainly of albite granite, subordinate trondhjemite and tonalite, and minor leucocratic granodiorite and quartz monzonite. The granite is unusual in that it consists almost entirely of quartz and albite-oligoclase, large parts of it being virtually free of mafics and K-feldspar. The pluton has a strongly foliated border and relatively massive core. Contact effects are slight. The Annette pluton and older sequence are unconformably overlain by rhyolite, the base of which is locally marked by conglomerate containing clasts of albite granite and older rocks. The rhyolite is conformably overlain by fossiliferous Upper Triassic limestone, and the limestone in turn is conformably overlain by a thick section of intermediate volcanics, graywacke, slate, and conglomerate that probably ranges in age from Late Triassic to Cretaceous. The Cretaceous (?) beds are cut by a quartz diorite stock on northern Annette Island, and there is a dunite-peridotite ultramafic body in contact with preplutonic sequence rocks south of Metlakatla.

Stratigraphic evidence for the age of the Annette pluton—heretofore considered to be Mesozoic—favors intrusion during the post-Devonian-pre-Late Triassic interval, and emplacement may have occurred prior to the Permian. The pluton is especially noteworthy because it is the first well-documented Paleozoic intrusive in the Wrangell-Revillagigedo belt, a geologic environment that contrasts strongly with the adjoining Prince of Wales belt, where several Paleozoic plutons are known.

PUERTO RICO

Age relations established for volcanic rocks

The work of J. M. Aaron and D. H. McIntyre extended detailed mapping in northwestern Puerto Rico from the area previously mapped by O. T. Tobisch westward to the sea (locality 1, index map). This new work, together with new fossil age determinations by K. N. Sachs, Jr., and E. A. Pessagno, firmly established the stratigraphic succession and ages of the volcanic rocks present in the area. Earlier work on Cretaceous mollusks by N. F. Sohl also provides excellent age data for one of the formations.

Six formations, ranging in age from Late Cretaceous (Campanian-Maastrichtian) to middle Eocene, now are recognized in northwestern Puerto Rico. A hiatus may separate the Cretaceous rocks from those of the Tertiary. All the units are dominated by debris derived from submarine volcanic eruptions from at least three different source areas. Compositions range from basalt to rhyodacite. All but two of the formations locally have yielded material rich in Foraminifera.

A large number of samples from the Río Culebrinas Formation, studied by K. N. Sachs, Jr., yielded a particularly abundant fauna of middle Eocene larger Foraminifera. In earlier, published estimates, the Río Culebrinas had been considered to be largely Late Cretaceous to Paleocene or early Eocene in age. Nearly all the species recovered are typical of the middle Eocene of Cuba and elsewhere in the Caribbean and Gulf Coast.

Sachs also reports that one sample from the Río Culebrinas Formation was found to contain abundant
well-preserved radiolaria. Unfortunately, attempts to free them from the matrix for specific identification have been unsuccessful. However, a middle Eocene age has been tentatively assigned to this material on the basis of larger Foraminifera identified in the Río Cu- lebrinas from nearby localities. If the age determination is correct, this represents the first reported occurrence of Eocene Radiolaria from Puerto Rico.

Metamorphic zone may overlie buried pluton

The Río Blanco Formation (Upper Cretaceous) of northwest Puerto Rico contains a roughly elliptical zone about 6 km long and wide (loc. 2) in which epidi-te-quartz veins are abundant according to D. H. McIntyre. The major axis of the zone coincides with a west-trending fault traceable for at least 26 km. The zone is surrounded by an aureole 1 to 6 km wide of pervasive incipient albite-epidote hornfels facies metamorphism, which is, in turn, bordered on the west and the south by zeolite facies rocks. The Río Blanco For­mation, particularly in the zone of epidote veins, con­tains numerous dikes of granodiorite porphyry, all meta­amorphosed to the same grade as the host rocks that enclose them.

The zone of epidote veins is the center of a post­thermal anomaly. It may be underlain at relatively shallow depth by a small granodioritic pluton. The granodiorite porphyry dikes probably represent early injections of granodioritic magma into cold wallrocks. Later hydrothermal activity, associated with the cooling pluton, and partly channeled by west-trending faults active at the time, resulted in the zoned meta­morphic aureole that affects both dikes and country rocks.

A pronounced aeromagnetic low occurs over the area of epidote veins, and an aeromagnetic high is located over the zeolite grade rocks. The pattern of meta­morphism helps explain the aeromagnetic data, and the data may help outline similar patterns of alteration elsewhere in this area of deep tropical weathering.

One occurrence of small gold-quartz veins, discovered by McIntyre during mapping in the area, is located near the major west-trending fault, and about 0.8 km west of the zone of epidote veining. Further outlining of the alteration pattern will aid the search for other occurrences of this type in the area.

Miocene rocks thicken downdip toward Atlantic Ocean

Geologic mapping of the Arecibo quadrangle, nor­thern Puerto Rico, (loc. 3) by R. P. Briggs (r0256) demonstrated that the Aguada Limestone of Miocene age and other middle Tertiary units thicken northward, downdip, confirming data previously derived from cut­tings from a dry oil test well near the Atlantic coast. The Aguada was found to thicken from about 90 m, in the southern part of the quadrangle, to about 180 m, 8 km to the north, or at the rate of about 10 m/km.

Mineralogy of beach sand reported

Along the Atlantic coast of the Arecibo quadrangle, R. P. Briggs (r0256) reported that mineralogy of beach and eolian sands changes abruptly at Purta Morillos. To the west, quartz sand predominates, to the east calcium carbonate sand. The quartz sand is de­­rived from batholithic rocks of the interior of Puer­to Rico, whereas the calcium carbonate sand is derived locally, chiefly from the shells and skeletons of marine organisms.

Post-Miocene faulting

Detailed geologic mapping by W. H. Monroe in the Penuelas quadrangle (loc. 4), showed that the middle Tertiary rocks are complexly faulted in contrast to the middle Tertiary rocks in northern Puerto Rico. A series of en echelon faults forms the boundary at most places between these rocks and the volcanic rocks of Cretaceous and early Tertiary age; the middle Tertiary rocks generally dip north toward the faults. Oth­er faults farther south cut only the middle Tertiary rocks.

GEOLOGIC MAPS

Much of the geological and geophysical work of the U.S. Geological Survey consists of mapping specific areas, mostly for publication as quadrangle maps at scales of 1:250,000 1:62,500, and 1:24,000. Some of these studies are for the purpose of extending geologic knowledge in areas of known economic interest; some are to gain detailed knowledge for engineering planning or construction. Still other mapping studies are carried on with solutions to problems in 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.

LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes about four-fifths of the geologic-mapping program of the Geologi­cal Survey. Geologic maps at a large scale are available for slightly less than one-quarter of the conterminous
United States. Approximately half these maps have been produced by the Geological Survey; the remaining maps were produced mostly by various State organizations and educational institutions. The ultimate goal is to obtain complete detailed geologic map coverage of the entire Nation.

The Geological Survey is carrying out large-scale geologic mapping projects in many parts of the country, with intensive cooperative programs underway in Kentucky, Massachusetts, Connecticut, and Puerto Rico. Other areas where extensive mapping is underway include Arizona, California, Idaho, Montana, Michigan, New Mexico, and Washington.

Large-scale geologic maps play a vital role in furthering scientific knowledge of the earth and have many uses. Maps of mineralized areas are used to (1) explore for and locate economic mineral deposits, (2) elucidate the scientific principles that underlie formation and distribution of ore deposits, and (3) prepare reserve and resource estimates.

Geologic maps are used extensively in planning and carrying out large-scale engineering works such as locating damsites, planning highway alignments and subway routes, and so forth. Actual construction is aided through location of construction materials and estimation of costs in site preparation. In some areas, geologic maps are indispensable in avoiding such hazards as landslides, swelling clays, and those areas possibly subject to extensive seismic damage during earthquakes.

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 makes up an important part of the Geological Survey's geologic-investigations program. The 1:250,000 and smaller scale geologic maps generally are based upon the generalization of available large-scale geologic maps supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to a point where it constitutes about one-fifth of the geologic-mapping program of the Geological Survey. Many State geological surveys also have 1:250,000-scale geologic-mapping programs which are underway or completed. These efforts by the Federal and State surveys as a nationwide program promises to provide geologic-map coverage of two-thirds of the United States by 1985; at the present time about one-third is covered.

The Geological Survey is participating in 1:250,000-scale geologic-mapping programs that will provide extensive or complete coverage of Alaska, Nevada, Colorado, and Nebraska within a few years. Single-sheet 1° by 2° geologic maps have been started in parts of Washington, Oregon, Idaho, Montana, Wyoming, Utah, Arizona, New Mexico, Iowa, North Carolina, South Carolina, Tennessee, and Virginia. Figures 2 and 3 show the areas of the United States for which 1:250,000-scale maps have been published.

The 1:250,000-scale geologic maps have a variety of uses. They help define areas where the need for larger scale maps is most critical, and they direct attention to broad geologic problems involving large segments of the earth's crust. They have already proved to be ideal for geologic analysis of major tectonic and stratigraphic problems, for analysis of mineral provinces, and for relating broad geophysical anomalies to surface geology.

MAPS OF LARGE REGIONS

Published in 1969

Tectonic map of North America, scale 1:5,000,000, compiled by P. B. King (1967).


Geologic map of Arizona, scale 1:500,000, by E. D. Wilson, R. T. Moore (both of Arizona F- reau of
GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE STUDIES

Mines), and J. R. Cooper (U.S. Geological Survey) (r2380).

Shows about 75 geologic map units in color, fold axes, and faults on a topographic base. Replaces map published in 1924 and long out of print.

Geologic map of Oregon, scale 1:2,000,000, compiled by G. W. Walker and P. B. King.9

Simplified map showing 17 map units and published as U.S. Geological Survey Miscellaneous Geologic Investigations Map I-595.

Geologic map of Washington, scale 1:2,000,000, compiled by A. E. Weissenborn (r1578).


Generalized geologic map of the northern Appalachians, scale 1:2,500,000, compiled by W. S. White (r0066).

The Appalachians from the Delaware River to the Gulf of St. Lawrence shown with 11 map units in black patterns, released in open file in 1968 at 1:1,250,000 scale. In 1969, same map at 1:2,500,000 scale with black and red patterns published in "Studies of Appalachian Geology, Northern and Maritime" by E-an Zen, W. S. White, J. B. Hadley, and J. B. Thompson, Jr., editors, John Wiley and Sons, publishers, New York.

Tectonic map of central and southern Appalachians, scale 1:2,500,000, compiled by J. C. Reed, Jr.


In preparation in 1969

Metallogenic map of North America, scale 1:5,000,000, P. W. Guild, compiler.

A contribution to the Metallogenic Map of the World sponsored by the Commission for the Geological Map of the World of the International Geological Congress and International Union of Geological Sciences. First hand-colored draft completed in 1968 from material supplied by a committee representing geological surveys and equivalent organizations of Canada, Central America, Mexico, Greenland, and the United States. Shows major known deposits of metal-bearing and nonmetallic minerals and their geologic-tectonic settings. A coproduct of the map compilation will be computer storage of data on deposits to facilitate rapid retrieval.

Metamorphic map of North America, scale 1:5,000,000.


Preliminary metamorphic map of the Appalachians, scale 1:2,500,000, in compilation by B. A. Morgan, III.

First unit in a planned map of North America. Shows biotite, garnet, staurolite, kyanite, andalusite, and sillimanite in pelitic schists, areas of greenschist and amphibolite mineral facies, and metamorphic facies series characterized by andalusite-sillimanite and by kyanite-sillimanite transitions.

Geologic map of the United States, scale 1:2,500,000, recompilation by P. B. King assisted by H. M. Beikman.

More than two-thirds of conterminous United States has been plotted in preliminary form. New compilation will supersede existing map published almost 40 years ago.

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Figure 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published as of June 30, 1969.
FIGURE 3—Index map of Alaska, Hawaii, and Puerto Rico showing 1:250,000-scale geologic maps published or open-filed as of June 30, 1969.

EXPLANATION

Published by U.S. Geological Survey
Published by State and other agencies

A59
WATER RESOURCES

The U.S. Geological Survey conducts surveys, investigations, and research on occurrence, quality, quantity, distribution, and movement of surface and underground waters that comprise the Nation's water resources, and on the sediment discharge of streams. Activities of the Survey include the systematic collection, analysis, and interpretation of data relating to the evaluation of national water resources, and investigation of water demand for industrial, domestic, and agricultural purposes. Research and development to improve the scientific basis of investigations and techniques are important functions; results are published in many scientific publications or released to the public in other forms.

Surface-water studies during fiscal year 1969 included collection and analysis of streamflow, flood, and quality-of-water data. Data on streamflow were collected at about 8,500 stream-gaging stations, nearly 5,900 of which are equipped with digital recorders, and at some 900 lake- and reservoir-level stations. Some 1,500 maps showing flood-prone areas were published in 1969, largely in the Hydrologic Investigations Atlas series. A rapid expansion occurred in quality-of-surface-water studies—currently, at approximately 3,000 water-quality stations in the United States and its possessions, parameters measured include selected major cations and anions, specific conductance or dissolved solids, pH, and selected quality characteristics. Other parameters, measured as needed, include trace elements, phosphorus and nitrogen compounds, detergents, pesticides, radioactivity, phenols, biological oxygen demand, and coliform bacteria. Streamflow records are collected at most of the water-quality stations, and water temperature is either recorded continuously or at the time of sampling at the 3,000 water-quality stations. Sediment data are obtained at 705 locations.

Daily measurements of ground-water levels were made in about 2,400 wells, and periodic measurements in about 24,000 wells. About 1,000 areal water-resources studies and some 600 research projects are now in progress. The total area in the United States covered by studies of ground-water resources amounts to about 2 million sq mi or nearly two-thirds of the country. About 185 of the areas studied in 1969 were urban areas. In addition to the studies of fresh water, studies of saline ground water and brackish water in estuaries are being carried out.

The Geological Survey is responsible for a national water-data network, which is operated with the cooperation of State and Federal agencies and which provides basic data on the status of the Nation's water resources. Included among these observation stations are about 57 hydrologic bench-mark stations, where the effect of man's activities is slight and where long-term hydrologic observations will be made. Radioc-chemical analyses, in which alpha, beta, radium, uranium, tritium, and radioactive carbon determinations are made, are performed at about 45 of the bench-mark stations at monthly or quarterly intervals. Analyses for pesticides are also made at these stations, and at least 2 samples per year are collected at more than 40 stations.

About 51 of the water-measurement stations are maintained as part of the Nation's participation in the International Hydrologic Decade program. Daily measurements are made at 10 of the stations, and monthly or periodic measurements at the remainder.

The use of computers for studying hydrologic systems and for storing data expanded greatly in 1969. Records of about 165,000 station years of streamflow data and information on some 25,000 ground-water wells are now available on a set of 24 magnetic tapes.

Studies of land subsidence, including studies in many areas only recently affected by subsidence, and of ground-water recharge for countering both subsidence and depleted ground-water resources, continued on an expanded scale.

The principal publications for basic hydrologic data are in the following series of U.S. Geologic Survey Water-Supply Papers: (1) "Surface-Water Supply of the United States," (2) "Quality of Surface Waters of the United States," and (3) "Ground-Water Levels in the United States." In addition to these basic-data reports, other series of Water-Supply Papers describe the magnitude and frequency of floods for the entire country, by drainage-basin areas, and total floods each year.

Investigations stressing the economic aspect of water as a resource are treated in the following section under the four regions (fig. 4), which correspond to the administrative subdivisions of the Water Resources Division.

ATLANTIC COAST REGION

The Atlantic coast region is generally characterized by the availability of moderate to large supplies of water and many highly populous urban centers. The irregularities of quantity, quality, and distribution of the water resource in and near these centers are growing more and more important and tend to magnify the interaction between people and their environment. Droughts, floods, salt-water encroachment, and municipal and industrial pollution of surface and ground water are all typical problems that must be considered
for an increasingly demanding society through knowledge gained of an increasingly complex system. Water development and management decisions for the solution of many of these problems require data and interpretations obtained from investigations by the U.S. Geological Survey, some of which are described below.

NEW ENGLAND

Water resources of Deerfield River basin, Massachusetts

Mapping of the bedrock surface in the Connecticut Valley lowlands portion of the Deerfield River basin in northwestern Massachusetts by L. G. Toler, F. B. Gay, and B. P. Hansen disclosed the typical U-shaped glaciated valley profile and the presence of several tributary hanging valleys. Bedrock elevations in the Deerfield River valley range from a few feet below sea level in the vicinity of Deerfield to more than 200 feet below sea level just south of Bernardston in the northern part of the valley. The valley is filled mostly with fine-grained glacial lacustrine deposits, to depths of more than 200 feet in places. However, in the northern part of the valley, substantial amounts of coarse sands and gravel supply about 1.5 mgd of water to the town of Greenfield.

Hydrology of upper Connecticut River basin, Connecticut

The bedrock underlying most of the upper Connecticut River basin in north-central Connecticut is sandstone, shale, and basalt of Triassic age. In many places the bedrock is overlain by clay and silt deposits, which are veneered with 5 to 20 feet of fine to medium sand. The specific capacities of many wells tapping sandstone and shale were determined by R. B. Ryder, D. A. Olin, and L. A. Weiss to be greater than 1 gpm per foot of drawdown, and a few are greater than 5 gpm per foot of drawdown. Water in the bedrock ranges in carbonate hardness from 77 mg/l to 930 mg/l, in noncarbonate hardness from 14 mg/l to 719 mg/l, and in sulfate concentration from 19 mg/l to 1,029 mg/l.

Preliminary analysis indicated that the flow characteristics of a stream draining a basin underlain by clay and silt are similar to the characteristics of a stream draining a basin underlain by till. During water year 1968, the range in daily runoff from a basin underlain by stratified sand reflected the large storage capacity of the aquifer. The highest daily mean discharge was 5.5 cfs per sq mi, or only about 4 times the lowest daily mean discharge and about 3 times the annual mean discharge.
Water resources of southwestern coastal river basins, Connecticut

Runoff to Long Island Sound from coastal river basins in southwestern Connecticut, as determined by R. B. Ryder and M. P. Thomas, is approximately 183 billion gallons during an average year. In 1965 about 16 percent of this amount of water was used by public water-supply systems in this largely suburban area.

Five areas underlain by stratified-drift aquifers are considered favorable for large-scale development of ground water. These areas are located in the Mill River valley in the town of Fairfield, the Saugatuck River valley in the town of Westport, the Norwalk River valley in the town of Norwalk, the Noroton River valley in the towns of Darien and Stamford, and the Ripowau River valley in the town of Stamford. The estimated potential yields from these areas that can be expected 7 years out of 10 range from 2.5 mgd to 7.3 mgd. In some places individual wells yield more than 2,000 gpm.

Stream water and ground water range from very hard in areas underlain by silicious marble to soft in areas underlain by deposits of stratified drift and some types of crystalline bedrock. The concentration of dissolved solids in streams at low flow ranges from 55 mg/l to 880 mg/l. Concentrations are highest in urban areas near the shore of Long Island Sound.

Water resources of Pomperaug River basin, Connecticut

W. E. Wilson, E. L. Burke, and C. E. Thomas, Jr., prepared a map which shows the spatial distribution of transmissivity of the stratified-drift aquifer in the Pomperaug River basin in western Connecticut. Transmissivities range from 20,000 gpd per ft to 50,000 gpd per ft in two principal areas, one near Southbury village and the other near Woodbury village. In a small part of the Southbury area, transmissivity is in the range of 50,000 to 100,000 gpd per ft. Elsewhere in the basin, transmissivity is generally less than 20,000 gpd per ft.

Yields of wells tapping the stratified-drift aquifer in the basin may be substantially augmented by induced infiltration of streamflow. At many sites, the gravelly streambed of the Pomperaug River probably has a vertical permeability greater than 100 gpd per sq ft. The river is of satisfactory quality for most water-supply purposes. For example, specific conductance ranged from 85 to 170 umhos/cm during an 18-month period of continuous measurement, indicating a range of dissolved-solids content of 51 to 99 mg/l. At the stream-gaging station at Southbury (drainage area, 75.3 sq mi), the median annual 7-day low flow of the Pomperaug River is about 6 mgd and the annual 7-day low flow to be expected once in 20 years is about 3 mgd.

Water resources of the upper Housatonic River basin, Connecticut

Stratified glacial drift aquifers in the upper Housatonic River basin in western Connecticut, an important source of water, were studied by M. A. Cervione, Jr., D. L. Mazzaferro, and R. L. Melvin. Permeable sands and gravels in portions of the Still River valley and in the Housatonic River valley between the towns of Caanan and New Milford extend more than 100 feet below the water table. Forty industrial and public-supply wells tapping these deposits yield from 50 to 1,400 gpm. The median yield is 250 gpm.

Reduction of yields from wells in several parts of the basin has resulted from chemical precipitation and corrosion of well screens and from lowered rates of induced infiltration. Ground water ranges in hardness from 13 to 378 mg/l. Samples of water from 27 wells tapping carbonate crystalline rocks had a median hardness of 244 mg/l, and water from two-thirds of the wells was very hard. Water from 80 wells tapping noncarbonate crystalline rocks had a median hardness of 85 mg/l. This value is about 60 percent greater than the median hardness of water reported for similar rocks in eastern Connecticut.

NEW YORK

Availability of ground water near Olean

M. H. Frimpter reported that glacial outwash deposits in the Allegheny River valley near Olean in western New York form a water-table aquifer averaging about 80 feet in thickness. A recharge budget and storage analysis for this aquifer indicates that a sustained yield of more than 200 mgd may be possible.

Present (1969) development of this source is slight. However, two 20-acre well fields, with 6 wells each, are producing about 14 mgd for industrial use in the city of Olean.

Hydrogeology of western Mohawk River basin

Water-resources investigations in glaciated regions are traditionally oriented toward locating water-laid permeable deposits. In the western Mohawk River basin in north-central New York, the surface configuration of the bedrock under a stagnating ice sheet controlled the mode of melt-water discharge and, therefore, the distribution of resulting deposits. Field investigations by J. M. Whipple disclosed that major discharges from the basin, producing significant outwash deposits, occurred through southerly valley outlets to parts of the Appalachian Plateau. E-tensive
water-laid deposits are found near the limits of the glaciated area along the Adirondack Mountains on the northern border of the basin. In the central area, lake sediments and limited water-laid deposits commonly overlie till deposited during glacial stagnation, and evidence of high melt-water discharge is rare.

The bedrock morphology not only influenced the textural character, extent, and distribution of glacial deposits but also set up the hydraulic situation in which the deposits were formed. For example, many permeable deposits are found high on valley flanks. These high-level deposits do not receive recharge from present day streams, which are lower topographically.

**Water resources of Black River basin**

In the Black River basin in northern New York, studied by R. M. Walter and G. R. Ayer, large quantities of water are available which require little treatment before use. The main river valley separates two significantly different hydrologic environments. Water is particularly abundant in extensive glacial deposits to the east of the main valley, and storage in these deposits reduces peak flows and sustains high base flows in adjacent streams. Ground-water storage and base-flow rates are much smaller in the Tug Hill Plateau area west of the main valley. There, many streams go dry, or nearly so, each year in spite of average annual precipitation in excess of 50 inches. Snowfall accounts for as much as half of the annual precipitation in parts of the basin.

**Geohydrology of central Suffolk County, Long Island**

Subsurface exploration by Julian Soren of a 20-mile strip of the central part of western Suffolk County, Long Island, located approximately along the island's ground-water divide, indicated the presence of thick aquifers containing large amounts of fresh water. The Magothy aquifer, of late Cretaceous age, is the major water-bearing unit. It lies below a Pleistocene aquifer with good hydraulic interconnection, and above the Lloyd aquifer (late Cretaceous), with poor hydraulic interconnection. The Magothy aquifer consists of about 300 to 700 feet of unconsolidated beds of sand, gravel, and intercalated thin to thick beds and lenses of clay and silt. A coarse sand and gravel zone 150 to 200 feet thick, containing moderate to large amounts of interstitial clay and silt, lies at the base of the Magothy aquifer.

Downward percolation of precipitation is the source of recharge to the aquifers. The Magothy aquifer is readily recharged through the glacial deposits. In some areas the Magothy is cut by glacial-filled buried valleys which afford lateral recharge to the middle of the aquifer.

**NEW JERSEY**

**The Potomac-Raritan aquifer system**

Analysis of subsurface data by H. E. Gill shows that fluvial Potomac-Raritan sediments were deposited as ancestral channel fill and overbank deposits roughly perpendicular to the present course of the Delaware River southwest of Trenton. Preparing piezometric maps of the area indicate that these channel-fill deposits function as natural drains to the system. It also appears that significant amounts of vertical leakage occur from the overlying Englishtown and Mount Laurel aquifers.

Water-quality analyses from the Potomac-Raritan aquifers near Philadelphia, Pa., indicate that groundwater contamination moved 0.7 mile toward the southeast during the past 10 years. The tongue of contaminate water is presently moving beneath the Delaware River toward the center of heavy groundwater withdrawal in Gloucester County, N.J.

**Buried valleys in Union County**

Bronius Nemickas reported that buried glacial valleys, which were delineated in Union County, can be extended to previously delineated valleys in Essex and Morris Counties. In the northwest corner of Union County, the altitude of the bedrock valley floor is as low as 17 feet above sea level and the glacial drift is as much as 203 feet thick. In the north-central part of Union County, the buried valley floor is as low as 3 feet below sea level and the drift has a maximum thickness of 90 feet. The buried bedrock valley extending northeast from the center to the northwestern edge of Union County and then into Essex County is as low as 52 to 80 feet below sea level, and the glacial drift is as thick as 180 feet. The most productive aquifers in Union County occur as fill in the buried valleys.

**PENNSYLVANIA**

**Water resources of Lehigh County**

Mapping of the water table in the carbonate rocks of Lehigh County in eastern Pennsylvania by C. R. Wood, J. B. Lesinskiy, and H. H. Flippo, Jr., permitted delineation of the ground-water basins of large streams, the recharge areas of several third-magnitude springs, and the cones of depression around several quarries and a deep zinc mine. The water-table maps were used to predict the general subterranean path followed by about 32 cfs that enters the carbonate aquifer from the channels of Jordan and Copley Creeks. Aerial remote sensing has pinpointed many of the springs that discharge this water to the Lehigh River.

Losses of flow from the channel in the midreac of Little Lehigh Creek, which caused up to 5 miles of this
reach to go dry during the autumn of the past 6 years, are believed to result from structural changes of unknown origin that occurred in the carbonate aquifer primarily in the fall of 1959. The quantity of this seepage varies in response to seasonal conditions. The last flow returns to the stream through springs immediately upstream from the water-supply intake of the city of Allentown.

**Ground-water resources in Mercer County**

G. R. Schiner and G. E. Kimmel defined optimum well depths for maximum yields of good quality water in the Shenango and Stoneboro 15-minute quadrangles in Mercer County, western Pennsylvania. The Cussewago Sandstone yields fresh water where saline water is present in overlying formations. In several areas, valley-fill sediments are as much as 500 feet thick and well yields may be as much as 1,000 gpm.

Although high iron content and high hardness are common in the ground waters in this area, these problems can be eliminated in most places by casing off the upper bedrock formations and tapping the deeper bedrock.

**MARYLAND**

**Time-of-travel studies of Monocacy River**

K. R. Taylor directed three time-of-travel studies covering the entire length of the Monocacy River in Maryland, a distance of 57 miles. The Monocacy River originates in Pennsylvania, enters Maryland, and flows southwesterly to its confluence with the Potomac River.

If a pollutant were introduced into the river at the upstream end of the study reach, when the flow past the index gage at Jug Bridge near Frederick, Md., was 100 cfs, approximately 20 days would be required for the peak concentration of contaminant to travel to the mouth. The river would not be free of traces of pollution for more than 30 days.

Corresponding travel times through the 57-mile reach at an index flow of 700 cfs would be about 4 days for the peak concentration to arrive at the mouth and 5 days to clear the river.

**WEST VIRGINIA**

**Water resources of Little Kanawha River basin**

The annual water loss by evapotranspiration from the Little Kanawha River basin in the western part of West Virginia, estimated by G. L. Bain and E. A. Friel from the difference between long-term averages of precipitation and runoff, is about 27 inches. This amounts to approximately 60 percent of total precipitation. The average annual discharge from the basin is 1.35 cfs per sq mi, and the extremes of annual discharge range from about 47 to 165 percent of the average.

Wide variations in the quality and potential yield of ground water occur over short vertical and horizontal distances. The quality is principally influenced by rock type residence time, position in relation to oil and gas wells, and possibly by position relative to fracture traces. Potential yield appears to be controlled by location of a well relative to channel sands and the degree of fracture porosity.

**SOUTH CAROLINA**

**Characteristics of low streamflow in the inner Coastal Plain**

A study by F. A. Johnson of the low-flow characteristics of streams in the inner Coastal Plain war started during a drought from July to October 1968 and allows a general comparison with the conditions of the 1954 statewide drought. The Edisto River basin in the southwesterly part of the area sustained a low flow that was about three times that of the 1954 drought. Flow in the Congaree basin was about 1 1/2 times the 1954 flow. Streamflow in the Pee Dee and Lynches River basins in the northeastern part of the area was about the same as that in 1954, although some streams apparently had less flow.

Streams having most of their drainage in the Piedmont or lower Coastal Plain adjoining the inner Coastal Plain were significantly lower in runoff per square mile than those lying mostly within the inner Coastal Plain.

**GEORGIA**

**Ground water in Gordon, Whitfield, and Murray Counties**

A study of ground-water resources in Gordon, Whitfield, and Murray Counties by C. W. Cressler revealed that individual wells in this area rarely yield more than 300 gpm, and apparently well fields will be limited to a production of less than 800 gpm. However, supplies of 1,000 to 1,500 gpm are available from several springs, and the water is of a quality suitable for many industrial uses.

**Hydrology of the coastal area in the vicinity of Riceboro**

By hydraulic and dispersion studies, T. P. Dyar evaluated the waste buildup that will occur from the injection of an effluent into the North Newport River. The buildup will be mainly a function of location of the effluent source (miles inland), effluent discharge and loading rates, tidal fluctuations, fresh-water inflow (a dilutent), and dispersion rates. There is virtually no flow mechanism to convey waste material to the ocean; the principal conveyance is dispersion.
Continuing water-quality studies have defined the natural variations of the estuarine water chemistry in time and space. Ground-water studies have enabled prediction of the areal effects of the withdrawal of 10 to 50 mgd of fresh water from the principal artesian aquifer near Riceboro.

**Salt-water encroachment studies**

A review by H. B. Counts of water-level, pumpage, and chloride records collected during the past 9 years at Savannah in Chatham County shows that there has been little or no sea-water encroachment into the principal artesian aquifer. Pumpage was slightly less than 65 mgd for this period. Chlorides increased slightly in 4 outpost wells, decreased in 3 wells, and did not change in 2 wells from January 1960 to January 1969. The piezometric surface was also virtually stable during this time. If this regimen continues, the Savannah area would be expected to remain safe from salt-water intrusion.

D. O. Gregg reports that ground-water levels in the Brunswick area in Glynn County, eastern Georgia, reached historic lows in 1968. This accelerated the intrusion of brackish water into the aquifer in the Bay Street area. From 1963 to 1968, the chloride content of water from a well in this area increased at a rate of 128 mg/l per yr. During 1968, the chloride content of water from this well increased from 1,440 mg/l to 1,920 mg/l, almost 4 times the average rate. A brackish-water zone below the aquifer contained a maximum of 2,150 mg/l chloride in 1964. In 1968 this zone was sampled and found to contain a maximum of 3,350 mg/l chloride.

S. M. Herrick's study of drill cuttings obtained during E. A. Zimmerman's investigation of Colquitt County, coupled with aquifer tests and potentiometric maps, tends to support the concept of the Suwannee Strait extending northeastward across south-central Georgia. The cuttings indicate a thickening of the Oligocene rocks with a corresponding increase in the proportion of fine clastic material (mainly clay in a band across Colquitt County). In some of the few wells that completely penetrate the Oligocene, the Eocene Ocala Limestone was found to be absent. Preliminary evaluation of two aquifer tests indicates great differences in transmissivity on opposite sides of the, as yet, ill-defined band. Previously published potentiometric maps show a steepening of the ground-water gradient in the principal artesian aquifer in the approximate location of the band. In thus seems likely that the “Suwannee Strait”, previously postulated on the basis of faunal evidence, did exist in Eocene and Oligocene times and was the site of clay deposition during Oligocene time.

**FLORIDA**

**Softer water for Jacksonville**

G. W. Leve and R. W. Fairchild report that a new supply of soft ground water was recently found in the Floridan aquifer near the city of Jacksonville in northeastern Florida. Jacksonville presently uses water from the aquifer that contains between 280 and 300 mg/l hardness as CaCO₃. Large quantities of water containing less than 80 mg/l hardness as CaCO₃ were located in the aquifer about 10 to 15 miles south of the city's well fields. This naturally soft ground water will be further investigated to determine how it can be best developed for future municipal supplies.

**Geohydrology of Lake County**

A study by D. D. Knockenmus showed that the Floridan aquifer, which supplies most of the water for Lake County in central Florida, is about 2,000 ft thick and consists mostly of limestone and dolomite. Overlying the Floridan aquifer are 50 to 200 feet of Miocene to Holocene clastic sediment. Recharge to the Floridan aquifer occurs throughout the county, but is variable because of changes in vertical permeability of the clastic sediments. The Miocene materials, which make up the majority of the clastic sediments, are composed of marine and marginal marine deposits. The marginal deposits are medium to coarse sand whose median grain diameter ranges from 0.2 to 0.52 mm and whose laboratory coefficient of permeability ranges from 15 to 1,200 gpd per sq ft. The greatest thickness of these high-permeability deposits occurs on the Lake Wales ridge in concurrence with a deep water table, high relief, and little runoff. The marine deposits are made up of sand and clay layers which in places contain phosphorite pebbles. The finer sediment has a median grain diameter which ranges from 0.10 to 0.16 mm and a coefficient of permeability from 0.1 to 12 gpd per sq ft. The less permeable marine deposits are generally thinner than the marginal marine deposits and occur in areas with less relief, a shallow water table, and greater runoff. A map showing relative recharge potentials has been prepared which may be used in the development of a comprehensive land use plan for Lake County.

**Ground water in Indian River County**

A study recently initiated by L. J. Crain in Indian River County in east-central Florida found that the most important source of potable ground water is a surficial sand and shell aquifer ranging up to 100 feet in thickness. Recharge and discharge of the aquifer both occur locally.
The Floridan aquifer, which can supply much larger quantities of water than the shallow aquifer, contains water too high in chlorides in the more populous eastern part of the county to be acceptable to most people. Studies also tend to indicate that in some areas, because of heavy agricultural withdrawals, the salinity may be increasing and the pressure head declining in the Floridan aquifer.

**Hydrology of the lower Hillsboro Canal area**

A recently completed report by H. J. McCoy and Jack Hardee on the lower Hillsboro Canal area of southeastern Florida states that large enough quantities of fresh water can be withdrawn from the shallow permeable Biscayne aquifer in the interior part of the area to meet future demands without the threat of sea-water intrusion. Recharge to the aquifer is by local rainfall—more than one-third of the average annual 60 inches of precipitation reaches the water table—and by infiltration from controlled canals. The implacement of a salinity barrier on the El Rio Canal has aided in the prevention of sea-water intrusion into the expanded Boca Raton well field. The ground water is of generally good chemical quality except in areas adjacent to the coast and uncontrolled reaches of the Hillsboro and El Rio Canals where sea-water intrusion has occurred.

**Effects of water management in southern Florida**

A study of long-term rainfall-runoff data for three primary canals which traverse the Everglades in southeastern Florida showed that two distinct reductions in discharge to the ocean occurred as the result of construction and operation of water-control works of the Central and Southern Florida Flood Control District. S. D. Leach and Howard Klein found that the first reduction occurred in 1953 when the completion of the eastern levee system brought about a decrease in eastward surface flows from the Everglades. The second reduction occurred about 1958 when the operation of interior pumping stations and spillways began to divert to diked storage areas part of the surplus water that would have been discharged to the ocean. Total reduction of discharge to the ocean amounted to about 300,000 acre-ft per yr or about 25 percent of the flow that otherwise would have been lost through the three primary canals. Future water-management plans call for minimization of fresh-water losses to the ocean through the maximum utilization of inland water storage areas.

As the Central and Southern Florida Flood Control District's plan for complete management of the water resources of Dade County becomes a reality, benefits from this system are appearing. Because of the maze of canals, levees, conservation areas, and water-control structures, major flooding by torrential rains (41 inches) during the period May-June 1968 was averted. Water-level maps by F. W. Meyer and J. E. Hull indicate that peak water levels in areas south of Miami were several feet lower than those experienced under similar rainfall conditions before construction and operation of the canal system there.

**Population dynamics of aquatic animals**

Small fishes and aquatic invertebrates were quantitatively sampled, according to M. C. Kolipinski and A. L. Higer, on a monthly basis in the Shark River Slough of Everglades National Park in southern Florida from 1965 through 1969. Preliminary findings indicate that inundation for long periods results in (1) an abundance of small aquatic animals, and (2) the successful formation of wading-bird rookeries. The rate of recovery of aquatic populations after drought depends upon the severity of the drought and the duration of the period during which the aquatic habitats are dry.

**Potential ground-water development in western Collier County**

H. J. McCoy and H. J. Voegtle predict that the immediate water needs of the city of Naples, western Collier County, on the southwestern Florida coast can be met by expanding the municipal well field northward along the coastal ridge. Water-table contour maps developed from predicted drawdown curves indicate that this expansion will not have a deleterious effect on the ground-water supplies of the north Naples area. Additional studies indicate that future needs for ground water can be met by expansion of existing facilities or establishment of new wells along controlled canals of a newly developed drainage system inland from the coastal ridge.

**Salt-water contamination of ground water in the Venice area**

Horace Sutcliffe, Jr., and Geronia Bowman report that salt water contained in material dredged from a sea-level canal and hydraulically deposited on an upland area is now infiltrating a shallow artesian aquifer. This aquifer is the source of a part of the municipal water supply for the city of Venice, Sarasota County, west-central Florida. Several wells adjacent to the dredged material have already been abandoned, and the chloride content of their waters has exceeded 2,000 mg/l. The effects of this salt-water contamination continue to spread, and 12 additional wells in this field may have to be abandoned in the near future.
Decline of ground-water levels in Walton County

Irrigation of a newly developed 27,000 acre farming complex in Walton County, northwest Florida, with ground water caused water levels within a 15-mile radius to decline to record lows during July 1968. C. A. Pascale and C. F. Essig found that Floridan aquifer water levels declined 20 feet or more below normal at a community 6 miles south of the farm. Although water levels recovered to within 5 to 10 feet of normal between September and December after irrigation stopped, residents of the community have approved construction of a centralized water-supply and distribution system which includes a well deep enough to assure foreseeable water requirements. As recently as June 1968, wells in this area flowed under artesian pressure.

PUERTO RICO

Water resources of the Yabucoa Valley

The Río Guayanés basin in southeastern Puerto Rico has a drainage area of about 50 sq mi, 40 of which consist of mountainous terrane carved from the San Lorenzo batholith. R. B. Anders investigated the remaining 10 sq mi, which makes up the flat, alluvial Yabucoa Valley and which ends at the sea on a broad front. The alluvium of the valley is believed to be as deep as 200 feet and makes up the largest single aquifer along the eastern coast. The total pumpage from half a dozen wells is less than 1 mgd, considerably less than the potential yield of the aquifer. In an intensive study of streamflow in December 1968, at the beginning of the usual dry season, it was found that discharge to the sea was about 60 cfs, which is equivalent to 39 mgd. Base flow from the mountains was about 1.1 cfs per sq mi, and from the alluvium about 1.7 cfs per sq mi. The water was of good quality, with the highest conductance observed being 420 μhmhos.

MIDCONTINENT REGION

Water resources investigations in the midcontinent region are increasingly oriented toward water management and toward seeking new sources of supply, including water of marginal chemical quality that may be made usable by demineralization processes. Optimum management of water resources requires increased knowledge of the hydrologic system and how it operates, and therefore studies in progress are designed to resolve complex questions concerning the relation between surface water and ground water and attendant water-quality problems.

In response to water-management information needs, modeling techniques are used to simulate, under varying conditions, the effects of various projected rates of water withdrawal for both regional and local planning purposes. A regional model of the Sparta Sand aquifer in the Gulf Coastal Plain and several local models of municipal and irrigation supply sources in heavily developed areas are typical of these studies. Parallel studies are conducted to evaluate quantitatively the development potential of ground-water sources throughout the region, and to discover new and undeveloped sources of ground water.

Problems of urban planning and development present new and increasingly complex questions as to the role of water resources in the urban environment. Accordingly, much emphasis is being placed on an increasing array of problems of water supply, flooding, waste disposal, and artificial recharge to augment existing water supplies in major metropolitan areas.

The results obtained from some of the studies being made in the region are discussed in the following section.

INTERSTATE STUDIES

Geohydrology of the lower formations of the Claiborne Group

A map showing the areal distribution of various salinity categories of water in the Queen City Sand is intended by J. N. Payne to reflect the extensive flushing by upward leakage of fresh water from the Carrizo Sand that has occurred in Lasalle, McMullen and Webb Counties, Tex.

The maximum thickness of the Reklaw Formation is found in southeastern Lasalle, southwestern McMullen, and eastern Webb Counties, Tex., where the formation is more than 700 feet thick. A belt of high sand concentration (over 60 percent sand) in the Reklaw Formation extends from southwestern Lasalle County through central and southeastern Frio County into central western Atascosa County, Tex. The pattern of sand-percentage distribution and of maximum sand-unit thickness in the Reklaw Formation suggests beach and nearshore bar deposition.

Channel sand deposits occur in the Cane River and equivalent formations in southern Arkansas and north-central to southeast-central Mississippi.

Analog model analysis of the Sparta Sand

An inventory was completed of pumpage and water levels for the Sparta Sand in Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. By 1965 approximately 3½ trillion gallons had been pumped from the Sparta Sand since the latter part of the 19th century. In response to this pumpage, water levels have declined; the maximum decline in 1965 was about 300 feet at El Dorado, Ark. Analog analysis by J. E. Reed of the water balance for the Sparta Sand
shows that in 1965 only about 20 percent of the water pumped was depleting storage in the aquifer, and that the other 80 percent was balanced by induced recharge or intercepted discharge. Water derived from changes in vertical leakage was the largest item in the 1965 water balance, amounting to 60 percent of the pumping rate. Although large in total amount, when considered as an average over the entire area where the Sparta Sand occurs, the change in vertical-leakage rate is less than 0.1 in. per yr. Flow has also changed at the lateral boundaries of the Sparta Sand where its subcrop is overlain by alluvial deposits. Induced recharge or intercepted discharge at these boundaries was about 20 percent of the pumping rate in 1965.

MINNESOTA

New sources of ground water for irrigation

Irrigation has intensified in northern and central Minnesota over the past few years, resulting in an accelerating demand for ground-water supplies. Current studies, prompted by the need for detailed information, indicate the presence of major sand and gravel aquifers in the glacial deposits capable of yielding abundant supplies of ground water.

Electric analog analysis by G. F. Lindholm of the surficial outwash aquifer in the Wadena area indicates that as much as 23,000 acre-ft of water might be withdrawn each irrigation season for as long as 20 years without seriously lowering water levels. Large quantities of water that might normally be lost to evaporation and transpiration can be utilized by a controlled lowering of the water table. Additional water might be obtained for beneficial use by pumping ground water that would normally be discharged into streams.

The surficial sand and gravel aquifer in the Preston-Belgrade area according to W. A. Van Voast is as much as 65 feet thick and has a transmissivity of up to 60,000 gpd per ft. Estimated maximum well yields from the aquifer are more than 1,000 gpm in much of the area.

An analog model of the aquifer, simulating 30-day pumping periods and programmed according to theoretical maximum withdrawals, indicates that the aquifer will support withdrawals of about 20,000 acre-ft per irrigating season for at least 20 years. The model indicated that water removed from the aquifer and from lake storage accounted for less than 50 percent of all withdrawals. The remainder was diverted from stream baseflow and evapotranspiration.

Another study by W. A. Van Voast, in a 35-sq-mi area near Lake Emily, showed outwash sand and gravel deposits having a saturated thickness of more than 50 feet locally. Transmissivity values for the water-tappable aquifer are as much as 60,000 gpd per ft. The aquifer is recharged by streamflow and by precipitation, and contains an estimated 115,000 acre-ft of water in transient storage. Estimated maximum well yields are more than 600 gpm along much of the western edge of the area, and less than 100 gpm along the eastern boundary. The water is suitable for irrigation, but the aquifer will be susceptible to pollution from fertilizers.

H. O. Reeder reports that ground water suitable for irrigation is found in glacial outwash sand as much as 100 feet thick near Perham, Otter Tail County. Semiartesian conditions may exist in parts of the area, as several tests indicated quick response to pumping. Thus far a good ground-water potential is indicated for the area; however, the transmissivity of the aquifer varies widely (20,000–200,000 gpd per ft) in short distances.

Surficial glacial outwash deposits north of St. James, Minn. (Watonwan County), were evaluated by J. O. Helgesen as a source of water supply. Saturated thickness of the outwash sand and gravel is less than 30 feet over most of the area, generally limiting potential well yields to less than 100 gpm. A 48-hour aquifer test indicates transmissivity of about 20,000 gpd per ft and a storage coefficient of about 0.15. Total dissolved solids in water from the aquifer was about 300 mg/l, considerably lower than that for other aquifers in the area.

An appraisal by Helgesen of surficial glacial outwash near Little Falls, Morrison County, reveals sand and gravel exceeding 50 feet in thickness, particularly near the Mississippi River. Use of an analog model is being planned to aid in interpretation of the ground-water system.

Geologic mapping and augering undertaken by T. C. Winter and R. W. Maclay resulted in the discovery of a sand and gravel unit more than 100 feet thick east of Lawndale and north of Rothsay, Minn. The unit consists largely of medium to coarse sand and gravel. The western part of the aquifer interfingers with fine-grained glacial Lake Agassiz sediments, which probably accounts for the concentration of numerous springs in an area about 10 miles long in the Lake Agassiz basin.

WISCONSIN

Water supply in Cranberry Creek basin

In a 96-sq-mi area of mostly sedge marsh and forested swamp in Wood and Juneau Counties, central Wisconsin, surface-water storage is greatly depleted during the growing season. Cranberry growers here divert an average of 2.5 inches of water annually into this marshy area in order to replenish their reservoirs. They apply larger quantities of water to 2.5 sq mi of cranberry bogs in order to protect the cranberry.
frost and drought and to harvest the crop. According to a study by L. J. Hamilton, water supplies in this area can be increased, or the diverted surface water replaced by ground water—by constructing wells yielding as much as 1,000 gpm from unconsolidated lake and outwash deposits in the southern part of the area. However, ground water has excessive concentrations of iron and manganese and a pH that may be detrimental to cranberries. The quality of surface and ground water is otherwise good, and there is no evidence of pollution of surface water by pesticides. Water drained from cranberry bogs has higher-than-normal concentrations of phosphate that is leached from fertilizer.

**Water-deficient area in central Wisconsin**

Ground-water supplies from bedrock sources (Precambrian crystalline and Cambrian sedimentary rocks) in the border drift area of central Wisconsin generally were found to be inadequate for municipal and industrial needs. An investigation in progress by E. A. Bell and M. G. Sherrill indicates, however, that moderate supplies of generally good quality ground water are available from sand and gravel outwash in some of the preglacial bedrock valleys tributary to the Wisconsin and Black Rivers. Many of these channels are buried in the sense that they have a glacial till and (or) alluvial cover.

**Ground-water quality problems in Milwaukee River basin**

In the Milwaukee River basin, southeastern Wisconsin, a study by J. B. Gonthier showed that ground water is pumped extensively from glacial outwash deposits and dolomite and sandstone aquifers. In the deeper sandstone aquifer, encroachment of saline water has reduced the usefulness of the aquifer locally. Ground water in the glacial deposits and the Niagara Dolomite has been polluted locally by surface wastes.

**MICHIGAN**

**Water resources of Oakland County**

F. R. Twenter and R. L. Knutilla estimate that in 1970 about 100 mgd of water will be required by the Pontiac metropolitan area in Oakland County, and perhaps twice that amount by 1990. Much of this water, perhaps as much as 80 percent, will be diverted from Lake Huron by the Detroit Department of Water, and the remainder developed from ground-water aquifers and streams in Oakland County. Glacial deposits can yield as much as 400 gpm to individual wells, and the Marshall Formation as much as 1,000 gpm. Seasonal low flow of streams in the area limits their suitability for water supply; however, this can be augmented by providing reservoir storage. More than 450 lal^-s, many of which are being rejuvenated by dredging and by pumping from ground-water sources to maintain higher levels, provide recreational and aesthetic benefits as well as potential water supply.

**Ground water in Ontonagon County**

Most domestic water supplies in Ontonagon County in the Upper Peninsula, which is under investigation by C. J. Doonan and G. E. Hendrickson, are obtained from wells in bedrock, although wells in glacial drift are successful in some areas. Most wells in bedrock in the southern half of the county yield fresh water, but in the northern half of the county, especially near Lake Superior, most wells more than 75 feet deep yield salty water. The highland areas where bedrock crops out or is near the surface are generally unfavorable for obtaining water from wells. Several townships supply water from wells to consumers in unincorporated towns, but the largest public water supply, for the village of Ontonagon, is obtained from Lake Superior.

**OHIO**

**Correlation of carbonate rocks by natural gamma logging**

Natural gamma logs were used by S. E. Norris and R. E. Fidler (p. B158–p. B161) for determining the contact between the principal carbonate rock units in northwest Ohio—those of the Niagara and Cayuga Groups. Logs of the upper part of the Niagara Group, a dolomite of high purity, show a relatively low intensity of radiation and are almost featureless, in marked contrast to logs of the slightly less pure dolomite of the overlying Cayuga rocks. A characteristic change in radioactivity at or near the contact is identifiable on most logs in the study area. Data from approximately 26 wells, supplemented by that obtained from quarry exposures, have been used to construct a structure contour map which conforms closely to the known regional structure. This map will be a significant aid in the interpretation of the hydrogeologic system in northwest Ohio.

**INDIANA**

**Ground-water supply in Columbus area**

An electric-analog model of a sand and gravel aquifer in the Columbus area, Bartholomew County, helped F. A. Watkins and J. E. Heisel evaluate the water available for domestic and industrial uses. Projected water use for the area is 34 mgd for the year 2015. Analysis of the model indicates that more than this amount can be developed from the valley-fill aquifer. Simulated well fields were pumped for various periods, including a drought period of 1,000 days, and
analysis was made to consider the long-term effect of ground-water pumpage on the flow of Flatrock River.

**Water resources of upper White River basin**

A report on the upper White River basin being prepared by L. W. Cable, J. F. Daniel, R. J. Wolf, and C. H. Tate states that the most permeable aquifers are sand and gravel deposits of Quaternary age. However, limestone and dolomite formations also are sources of moderate quantities of water. Areas of best ground-water-development potential are where thick sand and gravel aquifers are adjacent to streams. Average effective recharge rates for these areas are from 400,000 to 500,000 gpd per sq mi.

The long-term average streamflow is approximately 0.9 cfs per sq mi. The 7-day 10-year low flow ranges from about 0.01 to 0.3 cfs per sq mi, with the main stem ranging from 0.10 to 0.13 cfs per sq mi. Ground water is a hard, calcium carbonate type, and in headwater areas surface water is of similar quality. The quality of the surface water deteriorates downstream, however, owing to the cumulative effects of sewage effluent.

**IOWA**

**Deep bedrock aquifers in southeastern Iowa**

Half of the 5,365-sq-mi project area in southeast Iowa is underlain by Mississippian and Devonian carbonate aquifers which contain water with from 3,000 to 5,000 mg/l of dissolved solids. In some localized areas, the concentration reaches 10,000 mg/l. However, moderate-to-large amounts of water with less than 1,300 mg/l of dissolved solids are available from the Cambro-Ordovician aquifer which underlies the entire area. R. W. Coble reports that the Cambro-Ordovician aquifer can be reached at depths of from 1,350 to 2,000 feet, and yields of 200 to 1,000 gpm are produced by individual wells.

**MISSOURI**

**Potential ground-water sources in northeastern Missouri**

A study of water resources in northeastern Missouri lead E. J. Harvey to conclude that ground water with 1,000 to 2,000 mg/l of total dissolved solids (usable for many purposes) may occur in parts of the area from the Lower Ordovician and Cambrian aquifers. The quality of the water in these aquifers does not meet the requirements of the U.S. Public Health Service for public supplies.

Buried glacial valleys, which have been defined in southeastern Iowa, are also thought to extend into northeastern Missouri. These buried valleys, largely unexplored in the area, may contain significant quantities of water.

**KENTUCKY**

**Possible faulting revealed by geophysical and drillers' logs**

Studies of subsurface geology and hydrology of the Jackson Purchase region by R. W. Davis and T. W. Lambert indicate that a fault with as much as 600 feet of displacement may exist between two water-supply wells at Hickman, Fulton County. Older municipal wells about 650 feet deep are completed in the Claiborne Formation. Recently drilled wells of the same depth about 1.8 miles to the southeast appear to be completed in the Wilcox Formation. The Kentucky Geological Survey reports that in the same general area a fault with displacement of 200 to 500 feet exists in the Paleozoic formations.

Additional data are needed to confirm the presence of the fault between the two municipal well fields and to evaluate its possible effect on the geologic and hydrologic properties of the prolific water-yielding aquifers of the Claiborne Formation in the western part of the Jackson Purchase region.

**Urban development affected by subsurface drainage system**

Royal Spring is the principal source of water for Georgetown, which is located about 14 miles north of Lexington, Ky. A study by D. S. Mull indicates that the subsurface drainage system that feeds the spring extends into the Lexington area and underlies a series of sinkholes trending east-southeast from Georgetown. Numerous sinkholes are developed in streambeds and drain water into the Royal Spring system. One stream loses about 77,000 gpd to subsurface drainage. Streams are commonly used for the disposal of sewage treatment-plant effluent and storm-water runoff. Because of the danger of polluting ground water at considerable distances from the sources of pollutants, local planning groups and urban developers are now considering the subsurface drainage system before beginning new developments or zoning for new industries.

**Relationship of ground water to geologic structure and solution pattern**

T. W. Lambert reports that subsurface movement of ground water in the southern part of the Bowling Green, Ky., area is northwestward from the Simpson County line toward Bowling Green and Barren River. The direction of subsurface flow is controlled by northwestward-dipping limestone beds. Most of the discharge is at a large spring, locally known as Lost River "outlet," on the west edge of Bowling Green. The opening of the spring is mostly concealed by the
water of Jennings Creek, which was impounded in 1872.

Several streams south of Bowling Green sink into subsurface channels that are connected to Lost River outlet. Rapid ground-water movement in the subsurface solution openings and channels permits the widespread distribution of bacterial and chemical pollutants. Rapid urban expansion into the countryside on the south edge of Bowling Green will increase the runoff of surface water into the numerous subsurface channels, thereby causing additional ground-water pollution. Silt-laden water may also tend to clog up the openings to the subsurface channels, causing local flooding.

Quality of ground water in Pennsylvanian aquifers in Western coal field

Ground water having a concentration of dissolved solids of less than 1,000 mg/l is available from basal or near-basal sandstone deposits of the Pennsylvanian System in parts of the Western coal field region. Hydrologic studies by R. W. Davis, R. O. Plebuch, and Harry Whitman indicate that the fresh ground water from depths as great as 1,000 feet is separated by shale beds from overlying Pennsylvanian sandstones containing brackish or saline water. On the basis of data from oil-field water-flooding operations and interpretation of electrical logs of oil and gas wells, the fresh water in the basal Pennsylvanian deposits is tentatively thought to be in the south half of Muhlenberg and the south third of Hopkins Counties. The water from basal Pennsylvanian sandstones becomes progressively more saline and impotent north of this area. The limit of occurrence of the fresh water is thought to be controlled either by faulting, orientation of the basal Pennsylvanian channels, or by a combination of the two.

TENNESSEE

Ground water in Center Hill Lake region

In test drilling in the chert and limestone formations in Dekalb County and adjacent counties J. M. Wilson and G. K. Moore found that potential well yields at several locations were much higher than predicted from previously available well data. For example, the yield of a test well at Smithville was nearly 200 gpm, whereas a cluster of domestic wells in the surrounding area yield only 15 to 40 gpm. Similar conditions were found at Cookeville, Gordonsville, and Silver Point. Studies indicate good possibilities of obtaining adequate amounts of ground water for some municipal and industrial uses in at least a part of the basin.

Cavernous carbonate aquifers in upper Stones River basin

A study by G. K. Moore and C. R. Burchett indicates that the solution cavities in upper Stones River basin, Rutherford and Cannon Counties, range from a fraction of an inch to several inches in height, from several tens of feet to several hundred feet in width, and from a fraction of a mile to several miles in length. One or more solution cavities occur nearly everywhere in the basin, as only 9 percent of the drilled holes are dry.

Locally, the solution cavities are nearly horizontal. Vertical joints, however, provide the avenues by which water recharges the cavities, and most of the water discharged from the cavities travels upward along open joints to the streams. Recharge is limited to specific areas, and the solution cavities function only as pipelines to carry water from the recharge area to the discharge area. Recharge to the cavities averages about 7 inches, or 210,000 acre-ft per yr.

A sizable percentage of the storage capacity of the solution cavities is below the level of the streambed because only a very minor percentage of the wells go dry during long periods of drought.

MISSISSIPPI

Deep sources of ground water in east-central Mississippi

Test drilling for military and community water supplies in Kemper and Noxubee Counties, Miss., confirmed earlier hydrologic studies which indicated the presence of fresh-water aquifers underlying the slightly saline aquifers presently used as sources of ground water in parts of several counties. According to E. F. Boswell, a 2,400-foot test well for a community supply in Kemper County yielded water having a dissolved-solids content of about 600 mg/l. The chloride content was less than 300 mg/l. In Noxubee County, a 2,100-foot military water-supply test well produced water having a dissolved-solids content of about 400 mg/l and a chloride content of 168 mg/l. The aquifer, more than 300 feet thick, is a sand-and-gravel unit in the Coker Formation (lower part of the Tuscaloosa Group). The shallower slightly to moderately saline aquifers are the McShan and Eutaw Formations and, in places, the Gordo Formation (upper Tuscaloosa) of Late Cretaceous age. Electric-log studies indicate the underlying Lower Cretaceous sand and gravel also are potential sources of fresh water in the same general area.

LOUISIANA

Abundant ground water in southeastern Louisiana

The Tangipahoa-Tchefuncte River basin, in St. Tammany and Tangipahoa Parishes, is one of the most
water-rich areas of the United States. D. J. Nyman and L. D. Fayard report that the artesian aquifers between 1,500 and 3,000 feet in the southern part of the area commonly contain water having from 50 to 100 feet of head, and the water quality is generally excellent, having little iron, almost no hardness, and low total dissolved solids.

All the aquifers in the Tangipahoa-Tchefuncte River basins have shown a decline in head. The shallow aquifers have been affected by agricultural use, channel improvement, and land drainage, whereas the deep artesian aquifers have been influenced by municipal and industrial use and unrestricted flow of many artesian wells. In the project and adjacent areas, it is estimated that 40 mgd flow to waste year round from flowing wells. The declines in water level in the aquifers used for municipal and industrial supplies are currently about 2 ft per yr.

ARKANSAS

Water resources of the Ozark Plateaus region

A reconnaissance study of the water resources of the Ozark Plateaus in northern Arkansas by A. G. Lamonds shows that large supplies of good-quality water can be obtained from streams throughout the area and from subsurface aquifers in the northern part of the area. Yields from wells tapping the exposed formations are small, but wells tapping two subsurface aquifers in the northern part of the area may yield as much as 500 gpm. Streams in the northern part of the area have high base flows and can furnish dependable water supplies with little or no storage. In the southern part of the area, large water supplies can be maintained only with the construction of storage reservoirs.

ROCKY MOUNTAIN REGION

Water supplies in the Rocky Mountain region are moderate to abundant in the area east of the 100th meridian and moderate to meager in the areas west of this meridian. Precipitation is the source of all replenishable water in the region. Consequently, variation in the distribution of precipitation has a profound effect on the amount of water available for man's use.

The continued growth of population centers, industry, and agriculture places an increasing demand on the available water resources of the region. The mild winters in the southern part of the region attract thousands of winter visitors; but, unfortunately, many of the wintering areas have only meager water supplies. The growth pressures have created problems not only in the development of water supplies but also in the protection of those supplies from pollution.

The accelerated use of water has not always been coordinated with the irregular distribution of the water resources of the region; thus, there are increasing incidents of overdevelopment and of water-quality deterioration. Even in areas of relatively abundant water supplies, the idea of unlimited water supplies of good quality is rapidly being proved false. Thus, water managers should be provided with information on the adequacy and permanency of a source of water before selecting it as a permanent supply. Otherwise, the overdevelopment of a water supply may result in abandonment of it, or the economic position of the user may be jeopardized by water rationing.

Projects of the Water Resources Division in the Rocky Mountain region are designed to satisfy the ever-present and accelerating demand for water information. The appraisal and problem-oriented projects provide the basic water facts on the water resources of the region, while the basic and applied research projects contribute significantly to fundamental knowledge in the science of hydrology. Almost all the known traditional techniques and methods of hydrology are employed by the projects to collect water data; in addition, many new advances in technology are adapted as their reliability is proven. Analog models and digital computers now are providing solutions to many complex water problems that were extremely difficult to solve by other methods.

The Geological Survey is continually remodeling its program to stay abreast of changing water problems. New or accelerated effort by the Survey is being applied to developing the artificial recharge of ground-water reservoirs, understanding and coping with the effects of urbanization on water problems, controlling organic loads of bays and estuaries, studying runoff from small drainage basins, placing stream-side monitors that provide continuous records of water-quality variations, and understanding and dealing with several other environmental problems associated with water. The digital computer is creating a strong impact on all aspects of water studies. Many water-data collection stations are equipped to record the data on tapes; later the data are fed directly into the computer system for processing, analysis, and storage.

The significant results obtained from the studies made in the region are presented in the following sections.

MONTANA

Ground water in stream valleys in southeastern Montana

W. B. Hopkins reports that test drilling in the valleys of Rosebud Creek and Tongue River, in southeastern Montana, revealed buried channels containing
saturated gravel. Water from these buried channels is hard, but it is usable for household and irrigation supplies. The buried channel of Rosebud Creek is about 60 feet deep and contains about 30 feet of sand and gravel. Locally, the base of the buried channel of the Tongue River is nearly 80 feet below the land surface, and the channel contains as much as 40 feet of sandy gravel. The gravel reportedly yields up to 400 gpm to wells.

**Water resources of the Billings area**

Investigation of the water resources of the Yellowstone River valley between Billings and Park City by A. W. Gosling showed that the major source of water for the area is the Yellowstone River, whose mean annual runoff approaches 5 million acre-ft at Billings. Potable ground water in the area is limited to alluvial valley-fill material which ranges in thickness from 40 to 60 feet. These deposits yield small quantities of fair to poor quality water to wells. The valley is underlain by more than 1,000 feet of Cretaceous shales that yield water of very poor quality, usually more than 10,000 mg/l total dissolved salts. The water supply of the Yellowstone River is adequate for projected future requirements of urban growth and industrial expansion in the area.

**Potential alluvial aquifer in southeast Montana**

Test drilling indicates a buried stream channel in the Powder River valley in Custer and Powder River Counties in southeast Montana, according to W. R. Miller. The channel ranges from 20 to 50 feet in depth, is up to 500 feet wide, and in places is 20 to 30 feet deeper than the present river channel. In southern Custer County, the buried channel consists of thin, discontinuous layers of poorly sorted sand and gravel interbedded with impermeable silt and clay. The total saturated thickness in Custer County is less than 10 feet; upstream, however, the total saturated thickness of sand and gravel is larger and locally exceeds 30 feet. Properly constructed and developed irrigation wells yield up to 900 gpm in Powder River County. Preliminary estimates indicate that the buried channel contains at least 2,000 acre-ft of ground water in storage between Moorhead and Powderville, Mont.

**Electric analog used to evaluate bank storage**

Previously developed geologic concepts were used by D. L. Coffin to construct an electric analog of Libby reservoir and associated aquifers in northwestern Montana. Preliminary model results indicate bank storage will be from 3 to 6 percent of active reservoir storage. The model shows the relative amounts of bank storage along various sections of the reservoir. Sections where the amount of bank storage is small compared to active reservoir storage may be eliminated from intensive field investigation. If a water budget for the reservoir can be measured accurately to 1 percent, then field data needed to evaluate bank storage independently need only be collected for about a third of the length of the reservoir. If the accuracy of the water budget is greater, then field-data collection can be reduced accordingly.

**NORTH DAKOTA**

**Ground-water resources identified in Benson and Pierre Counties**

P. G. Randich reported that initial test drilling indicated a preglacial channel nearly 400 feet deep across southern Pierce County, central North Dakota. The channel contains more than 100 feet of saturated sand and gravel in most places. Other glacial outwash deposits were found with an areal extent generally less than 20 sq mi and with 25 to 100 feet of saturated sand and gravel. The aquifers contain a sodium bicarbonate or calcium bicarbonate type water with total dissolved solids ranging from 250 to 500 mg/l. The contact between the Pierre Shale and Fox Hills Sandstone was found to be about 30 miles east of its previously known location. Only the upper 10 to 30 feet of the Fox Hills Sandstone is a productive aquifer. Large ice-shove blocks of Pierre Shale and Fox Hills Sandstone, 10 to 30 feet thick, were found in channels and along the distal sides of terminal moraines in the study area.

**A major aquifer in Walsh County identified**

According to J. S. Downey an area of about 28 sq mi was delineated in south-central Walsh County, northeast North Dakota, in which yields of over 500 gpm may be available from properly developed wells. Water quality is generally within the U.S. Public Health Service 1962 standards.

Near McVille, in southwestern Nelson County, test drilling was used to locate a buried bedrock valley complex. The fine-grained sand filling the valley has a saturated thickness of about 200 feet. Well yields of more than 300 gpm should be possible from this aquifer. Water quality is generally within the U.S. Public Health Service standards.

Test drilling indicated that there may be need for reevaluation of the mapped position of the Dakota Sandstone across eastern Walsh County.

**Aquifer tests completed of the Fox Hills and Hell Creek Formations**

Forty-nine aquifer tests were completed on flowing wells that penetrate the Fox Hills and Hell Creek Formations in Mercer and Oliver Counties, N. Dak., by M.
The values obtained for transmissivity ranged from 13 to 3,160 gpd per ft, and the mean is 541 gpd per ft. The values for hydraulic conductivity are low and have a mean of about 16 gpd per sq ft. The wells have an average specific capacity of about 0.2 gpm per ft of drawdown.

Buried channel discovered in Burke County

C. A. Armstrong reported that test drilling indicates a buried interglacial channel, nearly 500 feet deep, traversing northern Burke County in northwestern North Dakota. The channel generally ranges from 3/4 to 13/2 miles in width and contains as much as 171 feet of saturated sand and gravel in lenses. The stratigraphy indicates that there were at least three cycles of fluvial deposition separated by glacial advances. The deposits of sand and gravel more than 270 feet below land surface appear to be hydraulically connected, whereas the higher lenses appear to be separate.

The lower aquifer contains a sodium sulfate type water with 1,700 to 1,800 mg/l of dissolved solids. The upper aquifers also contain sodium sulfate type water, but the dissolved solids range from 2,000 to 3,500 mg/l.

SOUTH DAKOTA

Hydrogeology of Marshall County

A shallow water-table aquifer composed principally of outwash sands and gravels underlies about 35 sq mi in the southeastern part of Marshall County. A systematic program of test drilling and well inventory by N. C. Koch and W. L. Bradford indicates that the aquifer ranges in thickness from about 5 to 60 feet. The bottom of the aquifer is generally within 75 feet of the land surface, and depth to water in wells averages about 20 feet. The aquifer is virtually undeveloped except for two wells which supply the town of Eden.

Hydrogeology of Brown County

Preliminary data compiled in the early stages of a water-resources study of Brown County by N. C. Koch and W. L. Bradford indicate that two glacial aquifers of unknown areal extent are capable of providing large yields to properly constructed wells.

An artesian aquifer south of the town of Hecla lies from 100 to 180 feet below land surface. Irrigation wells developed in this aquifer have pumped as much as 1,000 gpm.

A water-table aquifer borders Elm Creek from the town of Ordway to a point about 5 miles upstream. In this area, there are numerous gravel pits from which sufficient quantities of water can be obtained for irrigation needs.

Water resources of Faulk, Edmunds, and McPherson Counties

The Fall River Formation of Early Cretaceous age is being rapidly developed as a ground-water source in north-central South Dakota. The formation consists of about 100 feet of loose to moderately cemented sandstones and is overlain by approximately 100 feet of shale (Skull Creek Shale). The formation is commonly confused with the Dakota Sandstone which overlies the Skull Creek Shale because both aquifers are primarily sandstone and contain water under artesian pressure.

The potentiometric surface of water from the Fall River Formation is about 700 feet above the potentiometric surface of water from the Dakota Sandstone. Also, the waters from the two aquifers differ in chemical quality. Water from the Fall River aquifer is a calcium sulfate type while the water from the Dakota aquifer is sodium and calcium sulfate type. A water-resources study of Faulk, Edmunds, and McPherson Counties by D. G. Jorgensen indicates that development of this aquifer is occurring in a manner similar to the development of the Dakota aquifer in that wells of unnecessarily high yields (30-150 gpm) are being constructed and allowed to flow freely. It is estimated that 90 percent of the water from these wells is not beneficially used.

Geohydrology of Mt. Rushmore National Memorial area

According to J. E. Powell, D. G. Adolphson, and J. J. Norton, a well in mica schist at Mt. Rushmore National Memorial, Black Hills, S. Dak., produced 7,300,000 gallons of water in 1968. The well, which flows when not being pumped, is influenced by a pegmatite rill which was intruded into the country rock. The sill acts as a dam and creates a reservoir of ground-water upgradient in a small drainage basin of about 400 acres.

The fractured mica schist aquifer penetrated by the well will sustain a pumping rate of about 70 gpm during times of normal precipitation. Water from the well is of excellent chemical quality, taste, and appearance. The volume of water is much greater than was formerly believed to be available from a mica schist aquifer.

Preliminary evidence suggests that mica schist may be extensively fractured in the vicinities of pegmatite intrusives.

Geohydrology of Charles Mix and Douglas Counties

According to Jack Kume rotary test drilling during 1968 in Douglas County in southeastern South Dakota revealed about 80 additional sq mi that is underlain by buried outwash aquifers. The total known area of outwash is now about 180 sq mi. The aquifers consist of 10 to 50 feet of sand and gravel at depths of 100 to 380
feet. The deposits are confined to a newly discovered branch of a major preglacial stream channel. The aquifers are artesian and contain water of the sodium calcium sulfate type with dissolved-solids content of as much as 2,300 mg/l.

Rotary test drilling in northern Charles Mix County revealed a narrow preglacial channel containing buried outwash. The aquifer consists of 10 to 50 feet of sand and gravel. The depth to the top of this artesian aquifer ranges from 150 to 230 feet below land surface, and depth to water is about 105 feet below land surface.

**Hydrogeology of glacial outwash between Sioux Falls and Dell Rapids**

Preliminary analysis by D. G. Jorgensen of data collected at the City of Sioux Falls well field indicated that the well field acts as an artificial-recharge system. Recharge is induced from the Big Sioux River as a result of the supply wells lowering the water level in the aquifer below the level of water in the river. This recharge accounts for more than half of the total water pumped from the well field.

Preliminary analysis also indicates that subsurface inflow from the adjacent till bodies is of a larger magnitude at the well field than subsurface inflow from the outwash aquifer itself.

**Geohydrology of Crow Creek and Lower Brule Indian Reservations**

Dependable shallow ground-water supplies cannot be obtained throughout most of the Crow Creek and Lower Brule Indian Reservations. In at least two-thirds of the area, the Pierre Shale is at the surface or is overlain by only a few feet of alluvium, loess, or glacial drift. Where thick deposits of unconsolidated material are found the deposits are mostly clay till.

L. W. Howells found that within the reservations the major outwash and terrace deposits in the Missouri River valley are relatively non-water bearing even though highly permeable and fairly thick (20 to 100 feet). The deposits are above river or reservoir level and drain rapidly because of their high permeabilities and the high relief of the underlying bedrock surface. Terrace and alluvial deposits capable of yielding sufficient water for irrigation have been found only in southeastern Hughes County at the east end of an area called the Pocket. The most dependable water supplies are obtained from artesian wells 900 to 2,500 feet deep.

**UTAH**

**Water supply adequate in central Wasatch area**

C. H. Baker, Jr., found that water supplies are generally adequate for present needs in most of the Heber-Kamas-Park City area. Nearly all of the irrigable land is irrigated with surface water from the upper Provo and upper Weber River systems.

The best ground-water aquifers are in the unconsolidated fill in Heber Valley and Rhodes Valley. The hydraulic conductivity of the aquifers ranges from 20 to 50 cu ft per day per sq ft, and the estimated specific yield is 12 to 15 percent. The valley fill is at least 300 feet thick under most of the two valleys and may be as much as 800 feet thick locally. An estimated 500,000 acre-ft of water is stored under water-table conditions in the upper 100 feet of valley fill in the two valleys. Lesser thickness of valley fill in Round Valley and Parley’s Park have similar hydrologic characteristics.

The consolidated rocks in the area also contain large quantities of water. Water in the consolidated rocks is mostly in fractures and solution openings. Most wells in the consolidated rocks produce only enough water for domestic use in single-family dwellings.

**Ground-water conditions in southern Utah and Goshen Valleys**

The most significant findings of the ground-water study by R. M. Cordova in southern Utah and Goshen Valleys are listed as follows:

1. Aquifers were traced from northern Utah Valley into the area investigated by the use of gamma-ray logging.
2. Aquifer tests showed that pumping from one artesian aquifer caused pressures to decline in the shallower artesian aquifers.
3. Apparently a significant amount of recharge to the valley-fill aquifers is by underflow from the consolidated rocks of the Wasatch Range and other adjacent mountains.

**Major springs in Utah evaluated**

Although the number of springs in Utah is not known, the locations of several thousand mapped or reported springs were compiled. Additional thousands of springs undoubtedly occur in remote mountain areas and unmapped areas. Most of the major springs are in or adjacent to the major mountain belt that extends from the Utah-Idaho state line on the north to the Utah-Arizona state line on the south. No first order springs (average discharge 100 cfs or more) occur in Utah. Maximum measured discharge of Mammoth Spring in southwestern Utah according to J. C. Mundorff was 314 cfs during a 3-year period; maximum discharge of Swan Creek Spring in extreme northern Utah has exceeded 200 cfs. Maximum discharge of most large springs in Utah occurs during or immediately after snowmelt in May or June. Dissolved-solids contents of the major springs are generally less than 500 mg/l, and many are less than 200 mg/l. All springs...
that had dissolved-solids contents of 500 mg/l or less were of the calcium bicarbonate or calcium magnesium bicarbonate type. The relatively few nonthermal springs having dissolved-solids contents ranging from 500 to about 2,500 mg/l were of mixed types ranging from sodium chloride to sodium-calcium-magnesium chloride bicarbonate.

Source of recharge identified in Spanish Valley

Reconnaissance study of ground water in Spanish Valley in southeastern Utah by C. T. Sumsion shows that the small mean annual precipitation on the valley and infiltration from streamflow is insufficient to account for the ground water consumed and discharged to the Colorado River. Recharge to the valley basin occurs by ground-water flow from higher areas in the La Sal Mountains where precipitation and recharge are greater. Annual ground-water withdrawals for irrigation and other uses are about half the estimated annual rate of recharge. Chemical quality of ground water in the valley is generally good; only in the lowermost part of the valley is it slightly harder than desirable.

Prolific aquifers in Cache Valley

According to L. J. Bjorklund and L. J. McGreevy the valley fill in Cache Valley, in northern Utah and southern Idaho, consists of Quaternary and Tertiary alluvial and lacustrine deposits as much as 5,000 feet thick. The fill includes extensive Quaternary gravel beds along the eastern half of the valley in the general area of Smithfield, Logan, and Hyrum. Yields to wells tapping these deposits are as much as 8 cfs to a pumped well and 6 cfs to a flowing well. A smaller alluvial aquifer, consisting of gravel and sand, along the western and northern margin of the valley in Idaho yields as much as 3 cfs to a pumped well. Ground water in both aquifers occurs under artesian and water-table conditions.

Quality of surface water in Bear River basin

Quality-of-water data collected for surface water during 1967–68 by K. M. Waddell and Donald Price and selected miscellaneous data collected previously at 124 sampling sites in the Bear River basin indicate the following:

1. The concentration of dissolved solids at most of the tributary sampling sites ranged from 100 to 500 mg/l; along parts of Sabratus Creek, Thomas Fork, Deep Creek, Big Malad, Little Malad, and Malad Rivers, the water had concentrations exceeding 1,000 mg/l. The comparatively high concentrations of dissolved solids at sites on the Malad River are attributed to inflow from highly mineralized springs.

2. The concentration of dissolved solids at main-stem sampling sites above Cutler Reservoir ranged from less than 100 to 750 mg/l; at main-stem sites below Cutler Reservoir, the concentration ranged from about 250 to 4,000 mg/l. The higher concentrations below Cutler Reservoir are attributed principally to inflow from ground water, the Malad River, and Salt Creek.

3. The highest concentrations of dissolved solids at most main-stem and tributary sampling sites were generally observed during the late irrigation and postirrigation periods.

Sediment data collected during snowmelt periods in June 1965 and May 1968 indicate:

1. Sediment concentrations due to snowmelt runoff were less than 200 mg/l at all main-stem sampling sites.

2. Battle Creek had the highest concentration of suspended sediment, with 4,010 mg/l.

Preliminary appraisal of National parks in Utah

Water-resources investigations in Canyonlands National Park by C. T. Sumsion and E. L. Bolke indicate water supply for park use is restricted by diverse geologic and hydrologic controls to small areas where ground water is of sufficient quality and quantity to be usable. In Dinosaur National Monument, the Weber Quartzite is an excellent aquifer where hydrologic controls are favorable; the quartzite aquifer has not been developed. A well in stream gravels of the East Fork Sevier River will provide additional water of excellent quality for Bryce Canyon National Park.

Hydrologic reconnaissance of Grouse Creek valley

J. W. Hood and Donald Price in a continuing study of western desert basins estimated average annual input to and output from the water-resources system in the Grouse Creek Valley, in northwestern Utah, to be 21,000 acre-ft per yr; of this amount, about 17,000 acre-ft is readily diverted. Most of the water in the system is of suitable chemical quality for domestic, stock, and irrigation use.

The source of water in the 430-sq-mi drainage basin is precipitation which averages about 276,000 acre-ft annually; almost all of this water is consumed by evapotranspiration within the drainage basin. Precipitation on lands above 6,000 feet provides both runoff to the 110-sq-mi valley area and recharge to the formations that underlie the valley. An estimated 7,000 acre-ft of runoff reaches the valley; of this amount, 6,000 acre-ft is probably available for diversion. A very small amount of surface water reaches the Great Salt Lake Desert south of the valley.
Although water is recharged to formations ranging from Precambrian to Holocene in age, the principal ground-water reservoir is in alluvial channel fill of limited areal extent and in consolidated sedimentary rocks of Tertiary and Quaternary (?) age. The channel fill is the most permeable, but the consolidated rocks contain most of the stored water. Recharge to and natural discharge from the ground-water reservoir is estimated to average about 14,000 acre-ft annually. Pumping of a few irrigation wells may divert a part of the natural discharge and has caused local water-level declines. Total average annual discharge is estimated to be 11,000 acre-ft through evapotranspiration, 2,000 acre-ft through wells, and 2,000 acre-ft by subsurface outflow to the Great Salt Lake Desert. Only about 3,000 acre-ft of nonbeneficial discharge is subject to salvage.

Most of the water in the Grouse Creek drainage basin is a calcium bicarbonate water with a low concentration of dissolved solids. The highest concentration observed (1,100 mg/l) was found in shallow water and probably is the result of evapotranspiration.

**COLORADO**

**Rapid ground-water development in northern High Plains of Colorado**

The number of irrigation wells in the northern High Plains of Colorado increased from 500 to 1,800 in the past 5 years (1963 to 1968) according to W. E. Hofstra and A. J. Boettcher. Changes in water level since 1964 indicate that discharge exceeded recharge in the area, and the average decline was about 2 feet. Near Burlington and south of Akron, however, the declines were as much as 10 feet.

**Evaluation of local overdraft of aquifer underlying Pueblo Army Depot**

Studies by F. A. Welder and R. T. Hurr showed how local overdevelopment of the aquifer underlying the Pueblo Army Depot, 5 miles west of Pueblo, Colo., can be relieved. The overdevelopment resulted from pumpage for the past 25 years of 6 closely spaced Depot supply wells. A cone of depression about 1 sq mi in area has been created around the wells, and in this depression the saturated thickness has been reduced by about 50 percent. As a result, well yields have declined to such an extent that peak demands cannot be met. Test drilling and analysis of well data have delineated areas where replacement wells can be drilled to relieve the overdraft of the aquifer in the present well field.

**Water-use pattern changed in South Platte River valley**

D. R. Albin, D. R. Minges, and P. A. Schneider, Jr., reported that increased utilization of the ground-water reservoir to regulate irrigation supplies significantly changed the pattern of water use in the South Platte River valley in Colorado. From 1930 to 1946, annual water use for irrigation averaged 890,000 acre-ft, nearly all of which was supplied by surface-water diversions. Since 1947, the annual use has averaged 1.2 million acre-ft; and, during dry years, as much as half of the water was pumped from wells. Utilization of the ground-water reservoir has helped the irrigation economy by providing a larger and more dependable supply. However, increased ground-water withdrawals have reduced return flow to the river, thus affecting surface-water rights and creating problems of water administration.

**Mining problems related to ground water in the Piceance Creek basin**

A study by D. L. Coffin, F. A. Welder, R. K. Glanzman, and X. W. Dutton (r2572) indicated that mines excavated into leached zones within the Parachute Creek Member of the Green River Formation may require pumping as much as 60 cfs to keep the mine de-watered. Water from the leached zone in the northwest-central part of the basin contains as much as 60,000 mg/l of dissolved solids. This highly mineralized water would present a disposal problem and would be of doubtful value as a saline water resource.

**Ground water in the Nussbaum Alluvium**

Gravel in the Nussbaum Alluvium overlain by colluvium or wind-blown silt and sand, covers parts of the Lamar 1:250,000-scale quadrangle in southeastern Colorado according to J. A. Sharps. This gravel, an important aquifer in the region, is underlain by shale of low permeability along a contact that dips generally southeastward. Springs and seeps occur along this contact where it is exposed on southeast-facing sides of valleys. It may be inferred from these data that ground water moves southeastward through the gravel and that water will be found where the gravel extends uninterrupted far enough updip to the northwest to provide an adequate catchment area.

**KANSAS**

**Pumpage increases in northwest Kansas**

E. D. Jenkins, T. J. McClain, and R. H. Pearl reported that the number of large-capacity wells that tap the Ogallala Formation and alluvium in 6 counties of northwestern Kansas increased 33 percent in the past 3 years, whereas, the amount of water pumped increased 50 percent. The number of wells in 1968 was about 1,200. The annual pumpage for 1966 was cor-
Pleistocene buried stream valleys

J. R. Ward reported that a major preglacial buried stream valley eroded into Upper Pennsylvanian bedrock was discovered in Atchinson County, northeast Kansas. It has a general west-to-east trend from south of Muscotah to Atchison. A few buried tributaries cut into the bedrock and join the major valley at the same base level. Other tributaries are hanging on the major valley, and are cut into glacial drift as well as bedrock.

The buried valley is filled by two tills of Kansan age which are separated locally by glacial outwash, and underlain by lacustrine and glacial outwash deposits. The thickness of the glacial drift in these valleys ranges from 0 to 250 feet. Water-table conditions predominate, but in four areas artesian conditions exist. Yields of wells in the water-table areas range from 0 to much as 250 gpm.

The largest artesian area is south of Muscotah on the east side of the Delaware River valley. The permeable glacial outwash deposits that make up the aquifer in this locality are confined above by relatively impermeable till and alluvium and below by the relatively impermeable bedrock walls and floor of the major buried valley. Artesian pressures are derived from recharge in upland areas to the east, where the bedrock surface abruptly rises to within approximately 20 feet of the land surface. Natural flows from wells range from 2 to 5 gpm, and several springs and swampy areas exist on the Delaware valley floor where the confining alluvium does not constitute a perfect seal.

ARIZONA

Water supply for Lake Mead Recreational Area

The Colorado River is the principal source of surface water and ground-water recharge in the drainage area along the east side of Lake Mohave. The permeable alluvium and fanglomerate deposits receive recharge from Lake Mohave, and the aquifers in the deposits adjacent to the lake are capable of yielding large amounts of water. A pump test was made by C. B. Bentley in a flooded mine to evaluate the hydrologic characteristics of a fractured granite aquifer and the production characteristics of the mine; the mine has several thousand feet of horizontal excavations. About 5.2 million gallons of water was removed from storage in the mine, and the mine was only partially dewatered.

OKLAHOMA

Hydrology of the Platt National Park area, Murrah County

Preliminary investigations by D. L. Hart, Jr., indicate faulting to be a major controlling factor in the quality and quantity of water discharging from springs and flowing wells in the Platt National Park area. Water from the two principal spring areas within the park, about 2 miles apart, has widely different characteristics. All the springs flow from a limestone conglomerate of Pennsylvanian age. Below the conglomerate a major fault in the pre-Pennsylvanian rock trends northwestward across the eastern edges of the park and appears to control the movement of water recharging the springs. Springs in the eastern part of the park are recharged by water moving into the conglomerate from an upthrown limestone of Ordovician age which is northeast of the fault. Individual springs in this area flow as much as 2,500 gpm. The water is primarily a calcium carbonate type with a total dissolved-solids content of 300 mg/l. Springs in the western edge of the park are recharged by highly mineralized water from rocks southwest of the fault that are younger than the Ordovician limestone. Individual springs flow less than 1 gpm. The water is primarily a sodium chloride type with a total dissolved-solids content of 4,000 mg/l. Water from springs and wells between the two main spring systems shows various degrees of mixing.

A reconnaissance of the water resources of the Tulsa quadrangle, northeastern Oklahoma

A hydrologic reconnaissance by M. V. Marcher of the Tulsa quadrangle, covering about 6,600 sq mi in northeastern Oklahoma, shows that several geologic units have considerable potential for development of ground-water supplies. Wells in the Roubidoux Formation yield up to 1,100 gpm of water in the northwestern part of the quadrangle and average about 300 gpm. The water is suitable for most uses as far west as central Craig County and as far south as central Delaware County, although in many areas it has a hydrogen sulfide odor. At Vinita, in southeastern Craig County, use of water from the Roubidoux is limited because of excessive amounts of chloride in the water.

Wells in alluvium along the Arkansas River in the vicinity of Tulsa yield up to 100 gpm. Terraces deposits in the same general area provide similar yields. Except for rather high hardness, water from these aquifers is of good quality.

Wells in Mississippian formations that underlie most of Ottawa, Delaware, Adair, and Cherokee Counties yield up to 25 gpm, and considerably more locally. The average yield, however, is about 5 gpm. The quali-
ty of water from the Mississippian rocks is generally good.

The Mississippian rocks are the source of numerous tubular springs. Yields of 25 large springs ranged from 70 to 3,600 gpm in September and October 1968; the total yield of these springs is about 25 mgd. The quality of spring water is good to excellent as it generally contains less than 500 mg/l of total dissolved solids. At present, few springs are used as a source of water, but they maintain the perennial streams of the area.

Rocks of pre-Mississippian age yield only limited amounts of water of generally poor quality.

Yields of wells in Pennsylvanian rocks, which underlie about three-fourths of the quadrangle, are generally less than 1 gpm, although yields of up to 10 gpm have been obtained locally from some of the thicker sandstone units. The quality of the water from the Pennsylvanian rocks is generally poor and in some places is unsuitable because of excessive chloride.

Geology and hydrology of the Oklahoma panhandle

Subsurface geologic investigations according to R. B. Morton have identified and outlined the distribution of the rocks immediately underlying the Ogallala Formation (Tertiary) in the Oklahoma panhandle. Preliminary information indicates that the Cheyenne Sandstone Member of the Purgatoire Formation and the Dakota Sandstone of Cretaceous age are important sources of irrigation water and should be tested as a possible source of additional water for the area. These aquifers in places would supplement the Ogallala aquifer and the lower part of the Dockum Group. The Cretaceous sandstone is present only in the western half of Cimarron County, and the lower part of the Dockum Group may prove to be a supplemental source of fresh ground water in Cimarron County and western Texas County.

D. B. Sapik reported that about 1,500 irrigation wells (December 1968) withdraw water from artesian and water-table aquifers in Cimarron, Texas, and Beaver Counties. Nearly 400 of these wells were put into use during 1967 and 1968. An estimated 10 percent of these wells tap the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation underlying western Cimarron County; some of these also produce water from the overlying Ogallala Formation, the principal aquifer in the Oklahoma panhandle. Annual water-level declines are not consistent over the area and range from 1 foot to more than 20 feet. The greater declines are in areas of high well density or in areas where the water-bearing materials are fine grained. Some of the greater declines are in northeastern Texas and northwestern Beaver counties where wells are developed in a perched water-table zone. Deep wells in this area drilled below the perched zone encounter poor quality water that has a range in specific conductance from about 1,200 to 3,000 μmhos/cm, percent sodium from 30 to 60, and sodium-adsorption ratios from 3 to 8. Wells drilled in southeastern Texas and southwestern Beaver Counties sometimes produce a poor-quality water which is similar to the water in the lower part of the Ogallala Formation in northeastern Texas County. Elsewhere, the chemical quality of ground water in the Ogallala Formation is generally suitable for irrigation. The water has a specific conductance of 450 to 900 μmhos/cm, percent sodium of 20 to 40, and a sodium-adsorption ratio of less than 3. Ground water in the Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation is of variable chemical quality and ranges in specific conductance from 350 to 900 μmhos/cm, percent sodium from 9 to 97, and sodium-adsorption ratio from 0.2 to 20. Where red beds in the panhandle are penetrated, the water is unsuitable for irrigation.

PACIFIC COAST REGION

Programs in the seven states of the Pacific coast region increasingly reflect the diversity of the physical environment as well as the advances in scientific methods available to the modern hydrologist. The habitat of water, be it the limestone plateau of Guam, a desert basin in California, or the flood plain of an Alaskan river, is under study through applications of new parameters and more sophisticated techniques.

Local projects in areas of rapid growth are attempting to forecast near-term water requirements, and then to discover new sources of supply or reevaluate existing sources for increased yield to meet the requirements. Larger scale studies, such as the study of the hydrology of the Columbia River Group in Oregon, Washington, and Idaho, will aid regional planning. Expanding recreational needs have called for investigations of potential water supplies at Crater Lake, Mt. Rainier, Sequoia, and McKinley National Parks, Glacier Bay National Monument, and the Whiskeytown National Recreation Area in California.

Concomitant with the areal studies are projects investigating individual topics such as water quality in Oregon and California and salt-water encroachment in Alaska and Hawaii. An increasingly important topic, especially relevant to California, is the assessment of the effects of large amounts of imported water on the ground-water reservoirs. The monitoring of streams and aquifers continues, adding to the base of inform-
tion upon which water planners can make decisions relating to longer periods of time. A notable trend in studies throughout the region is for greater quantification of the subsurface hydrologic system. Through increased density of the data-gathering network, and treatment of the data by means of computer modeling, the hydrologist can better evaluate the development and management of the subsurface reservoirs.

Significant results obtained by studies throughout the region are summarized in the following sections.

HAWAII

Rainfall-runoff relation on Haleakala

Mean annual rainfall on the northeastern and eastern slopes of Haleakala volcano on the island of Maui increases from about 50 inches at sea level to more than 350 inches in a wet belt between altitudes of 2,000 and 4,000 feet, and then decreases to less than 30 inches at the altitude of the crater rim, 10,025 feet. Preliminary studies by K. J. Takasaki and George Yamanaga show that more than 70 percent of the rain becomes streamflow, of which an average of 175 mgd is diverted along ditch and tunnel systems for irrigation of sugarcane on the relatively dry western slopes of the mountain. Little water reaches the sea as underflow.

Additional water for Wailuku area

A reconnaissance study by George Yamanaga and C. J. Huxel, Jr., showed that the most promising source of additional water in the Wailuku area of West Maui is a body of semiconfined water underlying older alluvium between the Waikapu and Waihee valleys. The permeable Wailuku basalt is the aquifer; the consolidated older alluvium, extending below sea level, is the confining layer. Present pumping from wells tapping this body averages 10 mgd of water with a chloride concentration of approximately 30 mg/l. A greater potential yield will be limited by salt-water contamination.

GUAM

Diverse hydrologic conditions on Guam

D. A. Davis and C. J. Huxel, Jr., estimated that unit recharge in the highly permeable limestone plateau of northern Guam is about equal to unit runoff in streams flowing from the relatively impermeable volcanic terrace of southern Guam, or about 2.5 mgd per sq mi. The total estimated recharge on the plateau is more than 100 mgd, but much ground water is lost to practicable development because of salt-water contamination.

ALASKA

Tides affect water supplies near Juneau

By measurement of water levels in three lines of test wells 1 mile apart across the valley of the Mendenhall River, J. A. McConaghy determined that tidal effects reach about 3 miles upstream from the low-tide line. During a tide with a 20-foot stage, a common high tide in the area, salt water transgresses about 2 miles upstream. Dissolved-solids concentrations in the river water 1.3 miles above the low-tide line range from 29 mg/l at low tide to more than 6,000 mg/l at high tide, contrasting with a concentration of approximately 4 mg/l of dissolved solids in normal river water. Many individual ground-water supplies already exist in the tide-affected area, reflecting the rapid urban development in the Mendenhall Valley around Juneau, and all are susceptible to salt-water contamination.

Water-budget analysis for Anchorage

A 5-year geohydrologic investigation of the Anchorage area yielded the following results during the third year of study: (1) Recharge to the artesian aquifer is about 50 mgd but may range from 32 to 89 mgd depending on evapotranspiration rates, according to a water-budget analysis, by W. W. Barnwell and J. B. Weeks, of the Anchorage artesian system that has been tested by analog modeling. (2) Data collected on Ship Creek by R. S. George and L. L. Dearborn reveal a seepage gain of 13 mgd below the gaging station at Elmendorf Air Force Base that probably is due to the return of underflow from above the gaging station. (3) One of two wells completed as part of a new contract drilling program was reported by Chester Zenone to have yielded 260 gpm for 47 hours with only 2.0 feet of drawdown. The well was drilled to a depth of 112 feet in the North Fork Campbell Creek alluvial deposits. A second well on the South Fork Campbell Creek alluvial fan did not penetrate an aquifer worthy of development.

Water supply will be adequate for Kenai Peninsula

The rapidly growing Kenai-Soldotna area will have ample water of good quality to supply domestic and industrial needs in the foreseeable future. According to G. S. Anderson and S. H. Jones the supplies are obtainable from the Kenai River after treatment to remove glacial sediment, and from ground water in areas favorable for high-yield wells. Although local areas with low yields and poor-quality water are present, ground water generally is being developed at a rapid rate.
Ground water abundant in Matanuska-Susitna area

A. J. Feulner reports that large supplies of both ground water and surface water can be developed to meet expanding needs in the Matanuska-Susitna area between Palmer and Talkeetna. Ground water is the preferable source because of the common necessity for desilting of surface water, and yields of 500 gpm to more than 1,000 gpm should be available from individual wells. The area of greatest potential for ground-water development appears to be within or near the flood plains of the major streams crossing the area. The chemical quality of both surface water and ground water is good; hardness is generally less than 200 mg/l.

WASHINGTON

Water levels continue to decline in east-central Washington

J. E. Luzier reported that irrigation pumping continues to cause water-level declines over a widening area of the basalt plateau near Odessa. A northwest-trending ground-water barrier, appearing to cross the area for a distance of 20 miles and causing an offset in water levels of about 200 feet, will have a serious, long-term effect on the decline problems. Rates of decline for 1967-68 were on the order of 6 to 12 ft per yr in upper aquifers, and 6 to 20 ft per yr in lower aquifers. The decline in the upper aquifers appears to be caused by continuous drainage through open well bores into lower aquifers which are heavily pumped for irrigation. Borehole logging has revealed a distinct temperature rise of as much as 6°F from aquifer to aquifer with increasing depth. The rise is related to the low vertical permeabilities of individual basalt flows. Overall permeability of the basalt is also relatively low, as reflected in specific capacities of 4 to 8 gpm per ft of drawdown for many deep multi-aquifer wells.

Possible pumped-storage reservoir site in Glade Creek valley

A study of the hydrology of the Columbia River Basalt in Oregon, Washington, and Idaho has shown that the lower part of Glade Creek Valley in southern Washington may be a feasible site for a pumped-storage reservoir. Evidence cited by R. C. Newcomb that the saucer-shaped desert basin, located between the Columbia Hills and Horse Heaven uplifts, is water-tight includes: (1) the general synclinal shape which would cause any potential leakage to move across the layering of the lava flows, (2) the presence of an impermeable tuff or tuffaceous clay layer beneath each of the top three lava flows, (3) the general lack of permeability indicated in water wells penetrating the top 500 feet of the basalt, and (4) places where leakage might occur through permeable strata down dip or along the strike of the beds are limited to controlable areas in stream gaps in the Columbia Hills uplift and in Patterson Ridge.

OREGON

Quality of surface water in Umpqua River basin

Surface water was reported by D. A. Curtiss to be of excellent quality throughout the Umpqua River basin. Concentrations of total dissolved solids ranged from 34 mg/l in Rock Creek near Glide to 118 mg/l in the South Umpqua River at Brockway. Tests during the irrigation season indicated no detectable amounts of pesticides or herbicides. Traces of boron were found throughout the basin, but the concentration was too low to affect use of the water for irrigation. Like those in other deciduous forest areas, streams showed high color values during early autumn and winter months.

Hot artesian water in Harney Valley

An investigation by A. R. Leonard showed that hot water from flowing wells and springs in Harney Valley is of the sodium bicarbonate type and has a dissolved-solids concentration of 400 to 550 mg/l. Concentrations of silica, boron, and fluoride were high; silica ranged from 70 to 90 mg/l, boron from 4.1 to 6.2 mg/l, and fluoride from 2.8 to 12 mg/l. Temperature of the water was 46°–80°C.

Sustained yields possible from perched water bodies at Crater Lake

A report by F. J. Frank and A. B. Harris on test drilling in Crater Lake National Park states that the regional water table is at an altitude of about 4,500 feet. Between altitudes of 5,000 and 6,500 feet, abundant springs are evidence for the occurrence of higher-level perched-water bodies, many of which appear to be recharged seasonally as shown by flow variations of the smaller springs. Flow from the larger springs, however, shows little seasonal fluctuation—Thousand Springs flowed 32.7 cfs in June 1968 and 33.2 cfs in September 1968. Such uniformity of flow suggests that the aquifers supplying the larger springs are capable of large, sustained yields.

NEVADA

Quantitative hydrologic studies

Water-resource reconnaissance studies were completed by T. E. Eakin, F. E. Rush, and P. A. Glancy during the year for 21 of the 253 hydrographic areas in Nevada. Water budgets, based on estimates of runoff, recharge, transpiration from phreatophytes, water use, and other factors, were established for each area as
part of the objective to obtain national coverage of quantitative hydrologic data. In addition, an index has been prepared that locates and described each of the 14 hydrographic regions and basins of the State as well as the 253 hydrographic areas. The 21 areas that have been studied quantitatively are: Alkali Spring, Northern Butte, Southern Butte, Clayton, Garnet, Northern Hidden, Southern Hidden, Ivanpah, Jean Lake, Lida, Lower Moapa, Mesquite, Steptoe, Thousand Springs Valley, California Wash, Oriental Wash, Stonewall Flat, Greasewood Basin, Black Mountains, Gold Butte, and Grapevine Canyon.

Bathymetric map of Pyramid Lake
A reconnaissance survey of Pyramid Lake was made by E. E. Harris and others in May 1968; it showed that the altitude of the water surface was 3,789 feet, at which level the lake has a surface area of 108,000 acres and a volume of 20.5 million acre-ft. Tables were computed showing the surface area and the volume of the lake at any level. The maximum depth of the lake was found to be 330 feet at a point 7 miles northwest of Anaho Island.

IDAHO
Bear River hydrology
A study by N. P. Dion showed that the channel of the Bear River between Alexander and Grace is losing water to the regional water table; some of this loss is regained from springs below Grace, but most eventually discharges into the Portneuf River. Water quality in the river has suffered because of diversion into Bear Lake for offstream storage. The water released from the lake generally is higher in dissolved solids than the river water. Although the water in Bear Lake apparently became more concentrated as the lake shrank from its maximum size during the Pleistocene, quality of the lake water has probably improved since the turn of the century with the addition of more-dilute Bear River water.

CALIFORNIA
Faulting controls ground water in Hollister and San Juan valleys
A study by Chabot Kilburn showed that widespread units of sands and gravel, along with more lenticular beds, make up the principal aquifers in alluvial fills of the Hollister and San Juan valleys in San Benito County. Faults affect the movement of ground water and have subdivided the valleys into several ground-water compartments. The Calaveras fault separates the Hollister Valley into two major ground-water compartments. Likewise, the San Andreas fault, which occurs along the southwest side of San Juan Valley, creates a small ground-water compartment along the southwest side of the valley in the San Juan Bautista area. Ground water on the eastern side of the Hollister Valley contains boron concentrations which in some areas may limit its usefulness for irrigation of boron-sensitive crops.

Additional water available in Santa Cruz County
J. P. Akers found that the Santa Margarita Formation has the potential for development of moderate additional ground-water supplies in Scotts Valley, Santa Cruz County. The formation, a medium- to coarse-grained sandstone 100 to 400 feet thick, is warped downward to form a syncline that plunges southeastward across the center of the area. In general, water entering the formation moves down the limbs and axis of the syncline to emerge as base flow in streams. The base flow, estimated to be about 3 cfs, plus whatever amount is lost to evapotranspiration, could be pumped from properly spaced wells in the Santa Margarita Formation without materially lowering water levels in the area. Recharge could be induced along the streams in the rainy season by pumping the wells in the dry season sufficiently to lower the water table below the level of the streambeds.

Outflow from Chino basin calculated
Annual ground-water outflow from Chino basin in the upper Santa Ana Valley during the period 1930-66 as evaluated by J. J. French ranged from a maximum of nearly 40,000 acre-ft in 1941 to less than 10,000 acre-ft in 1966. The outflow was calculated directly by a modification of the Darcy equation and also indirectly by means of a water-budget analysis. The reduction in outflow is attributable to an extended dry period and an increase in utilization, both of which began about 1945.

Nitrogen and phosphorus in Clear Lake
A study by W. D. Silvey and G. A. Irwin to determine the sources of the nitrogen and phosphorus in Clear Lake, the largest fresh-water body entirely in California, showed that the greater part of the two constituents originates in the upper watersheds of the lake's drainage basin. A second, less-important source is the agricultural area adjacent to the lake. A small additional amount is derived from the domestic wastes of small towns bordering the lake.

Electric-analog model to aid hydrologic study in Saugus-Newhall area
A geohydrologic study of the Saugus-Newhall area in the upper Santa Clara River Valley by S. G. Robinson revealed a two-layer aquifer system. This highly
permeable river alluvium of Castaic Creek, Bouquet Canyon, the Santa Clara River, and numerous tributaries forms a fingerlike stream that is underlain by the less permeable Saugus Formation. Most of the ground water is pumped from the river alluvium in which water levels have declined from a few feet to 75 feet or more during the period 1945-61. In view of the withdrawal that has already occurred, supplemental water will be necessary if the Saugus-Newhall area is to achieve its full economic potential in the future. To aid management in better utilizing imported water, an electric-analog model of the two-layer aquifer system is being constructed.

Water management in Mojave River basin enhanced by electric-analog model

An analog model by W. F. Hardt and S. G. Robson of the Mojave River basin was verified for the period 1930-63. Hydrologic questions proposed by management were programmed into the model, and the following results were obtained: (1) water-level changes due to projected pumpage up to the year 2000, (2) extremes in water-level changes caused by variations of flow in the ephemeral Mojave River, and (3) effects on the river system and nearby water levels in the aquifer of surface-water recharge at different rates from the California Aqueduct. The model emphasizes the importance of aquifer boundaries on the system. In the Barstow area the aquifer is extremely narrow, and water-level changes are greatly influenced by the availability of water in the Mojave River; elsewhere, the aquifer is much wider, and the river has less influence on water levels. The model indicates the time response and quantity of water needed to raise water levels beneath the river to the land surface, and to allow surface flow to move downstream to alleviate declining water levels in lower sections of the basin.

SPECIAL WATER-RESOURCES PROGRAMS

Desalination

Desalination, the process of converting brackish or sea water into sweet water, is one of the factors currently changing and expanding the U.S. Geological Survey's concepts of its responsibilities in water-resources investigation.

Private industry has been appraising the market potential for desalination. For example, the DuPont Co. gathered chemical analyses from more than 18,000 cities and towns in digital form for computer evaluation and found that 1,150 communities serving a population of more than 3.5 million had water supplies meeting the Geological Survey's definition of saline water. In most reports, the Survey defines saline water as that containing more than 1,000 mg of dissolved solids per liter of solution. Though drinkable by hardy persons in concentrations of 2,000 mg/l or even higher, water having a salinity above 1,000 mg/l becomes increasingly undesirable.

Desalination costs have decreased from about $5 per 1,000 gal 10 years ago to about $1 per 1,000 gal for sea-water distillation today. For membrane desalting of brackish ground water, costs now range from 60 cents to $1 per 1,000 gal. Projected costs for desalting in the middle 1970's are in the range of 25 to 50 cents per 1,000 gal. These are plant costs and do not include delivery to the consumer. In most of the country, water ready to drink can be taken from wells or surface-water filter plants for a few cents per 1,000 gal., but distribution costs bring the householder's bill to the 25 to 50 cents per 1,000 gal charged by many large cities today. One factor that makes it necessary to consider desalination seriously along with other water-management techniques is that the cost curve for water produced by conventional means is rising, while that for desalted water is declining as the technology is developed and improved. Inevitably in arid regions the curves will cross, and desalting will become practical even if costlier than might be considered desirable.

The places where desalination may become practical are numerous enough to justify a national look at the overall situation, and the Geological Survey is proposing a substantial effort to map saline aquifers and estimate the quantities of water available from them on either a long-term or a short-term basis.

Saline water—a valuable resource

Other uses for saline aquifers besides improvement of the Nation's future domestic water-supply situation through desalination are emerging. The pore space occupied by the saline water is a possibly useful medium for storing natural gas, for artificial recharge and recovery of fresh water stored as bubbles, or for storing industrial wastes. F. A. Kohout organized a symposium entitled "Saline Water—A Valuable Resource" for the April 1969 annual meetings of the American Geophysical Union at Washington, D.C. Papers considered the following subjects: distribution of saline water in the United States; experiences in and philosophy of deep-well waste disposal in saline aquifers; progress in desalting technology; quantitative mapping of salinity, volume, and yield of saline aquifers using borehole geophysical techniques; and methods of cost evaluation of imported conventional fresh-water supplies versus desalting of onsite saline water for both domestic and irrigation supplies. Considered also
were storage of gas bubbles in saline aquifers near metropolitan areas for recovery and supplemental use during the winter heating season, storage and recovery of fresh water in originally saline aquifers, and possibilities for stripping the chemicals from either oil-field or desalination brines. Among the papers presented were those by F. A. Kohout; J. H. Feth; W. L. Hiss; A. N. Turcan, Jr.; and A. G. Winslow and E. A. Moulder.

F. W. Meyer in reporting on test drilling in water-short areas in extreme southern Florida states that at least three artesian aquifers underlie the area within depths ranging from 400 to 1,300 feet. The hydrostatic pressure and the salinity of the contained water increase with depth. Large quantities of brackish artesian water containing 2,500 to 3,000 mg/l of chloride content are available at a depth of 1,300 feet. Biologic studies by M. C. Kolipinski indicate that some aquatic animals and vegetation can survive in this water and furthermore that the water is suitable for desalination. Data from the shallow artesian aquifers suggest that small quantities of less brackish water are also available.

T. M. Robinson reports that Tertiary marls and limestones and Quaternary alluvium of the central portion of St. Croix, U.S. Virgin Islands, contain large amounts of fresh-to-brackish water. In some areas, yields of a few hundred gallons per minute are possible. Treated sewage could be injected or infiltrated into these aquifers. The mixture of native and introduced water could be desalted to provide potable water at less cost than alternative methods.

**Quantitative mapping of saline water**

Saline water is known to underlie at least two-thirds of the United States at relatively shallow depth. In spite of this, there has been little quantitative mapping of saline aquifers because little value has been placed on this vast region of inner space. Though isolated water samples provide a qualitative indication of the occurrence of saline water, quantitative mapping requires that enough data be available to develop an altitude contour map of a particular isosaline surface. The most fundamental saline-water map is that of the altitude of the base of the fresh ground-water zone, which usually coincides with the top of the saline-water zone (1,000 mg/l). Such maps have been made of Ohio, Kentucky, Mississippi, Louisiana, and Texas and part of Tennessee, Alabama, Arkansas, and Oklahoma. This limited coverage shows the magnitude of work yet needed to permit enlightened choices among the various possible beneficial uses of saline aquifers.

The first extensive quantitative mapping of saline water was done in Louisiana by A. G. Winslow, D. E. Hillier, and A. N. Turcan (r2352). Using electric logs and an empirically developed field formation-resistivity factor, the altitudes of the 1,000, 3,000, and 10,000 mg/l isosaline surfaces were contoured, and the yields of these zones for standard conditions of well construction were estimated.

A. C. Sedam and R. B. Stein in studying Ohio's saline water resources mapped the base of potable water in the State's bedrock aquifers. In some parts of Ohio the base of the potable water zone includes water being used satisfactorily as a domestic potable supply that contains up to 3,000 mg/l of dissolved solids. In western Ohio, where the base of potable water is in Paleozoic carbonate rocks, the water is predominantly of the calcium magnesium bicarbonate type, but water of a strongly calcium magnesium sulfate type is present in some places. In eastern Ohio, where the base of potable water is in Paleozoic sandstones, the water is generally of a calcium bicarbonate type, although sodium chloride water is prevalent in some areas. In three sections of Ohio underlain by thick impermeable shales, the base of potable water is, for practical purposes, at the top of the bedrock surface at the base of unconsolidated glacial or alluvial deposits.

A pilot study is now underway under the leadership of T. E. Kelly of the U.S. Geological Survey to extend quantitative saline-water mapping to a much larger area. Because of the shortage of fresh water and the availability of saline water in the Rio Grande's region, this region was selected as the locale for a cooperative project between the Geological Survey and the Office of Saline Water both of the Department of the Interior. A major goal of the study is to outline areas of extreme fresh-water shortage and saline-water abundance in the 136,000-sq mi area.

Within the Rio Grande region, the Tularosa Basin (about 3,000 sq mi in area) was selected for a detailed study of the hydrologic and economic factors involved in introduction of desalination. The hydrologic factors are being explored by J. S. McLean (U.S. Geological Survey) and the economic factors by the New Mexico Water Resources Research Institute (NMWRRI) under the direction of H. R. Stucky. Funding for the study is shared by the U.S. Geological Survey, the Office of Saline Water, and the Office of Water Resources Research (all of U.S. Department of the Interior), and the New Mexico State Engineer and NMWRRI. McLean reports that reconnaissance gravity profiles of the Tularosa basin indicate the existence of north-south trending gravity lows south of Alamo-
gordo and west of Tularosa and Three Rivers. The gravity lows may be related to greater alluvial thicknesses in these areas. Electric logs and well-water analyses indicate that fresh to moderately saline water in wells along the eastern and southwestern margins of the basin is underlain by waters of higher salinity. Waters of moderately saline to brine quality are encountered at shallow depth through the central portion of the basin. It is anticipated that the detailed Tularosa study will have carryover value for analyzing future utilization of saline water in the much larger Rio Grande region and in similar regions elsewhere in the West.

DATA COORDINATION, ACQUISITION, AND STORAGE

Office of Water Data Coordination

Activities in coordination of water data, under guidelines of Bureau of the Budget Circular A–67, focused primarily on accelerated implementation of the circular, and development of an Interior Water Data System to serve the needs of the bureaus and offices of the Department of the Interior whose activities involve water. Agreements were reached on a computerized water-data handling subsystem and a subsystem for water-data acquisition. Within the latter framework, agreement was reached that the nucleus of the subsystem would be a network of continuing-type stations operated by the U.S. Geological Survey. A plan was agreed upon for development of standard field, laboratory, and office methods for collection and processing of water data acquired under the Interior Water Data System. Specific agreements were reached regarding responsibilities and work relations between the Federal Water Pollution Control Administration and the Geological Survey relative to water data activities.

It was further agreed that the actual details of coordination of water data would henceforth be carried out at the level of the 20 planning regions designated by the Water Resources Council. Implementation of this activity will begin on a pilot basis in several regions in fiscal year 1970. Data acquisition plans of the Federal agencies will be coordinated by regions and consolidated by the Office of Water Data Coordination into a single Federal plan for use by the agencies and by the Bureau of the Budget in preparing agency fund requests. The “Catalog of Information on Water Data” will serve as a primary vehicle for coordination.

Coverage under the “Catalog of Information on Water Data” has been extended to include ground-water observation stations, and areal investigations and miscellaneous activities of Federal and non-Federal agencies. Station listings in the surface-water and water-quality sections of the catalog have been updated as of July 1, 1968. The “Catalog of Information on Water Data” now comprises the following sections, with information as of July 1, 1968:

1. Surface-water stations reported by Federal and non-Federal agencies (index published).
2. Water-quality stations reported by Federal and non-Federal agencies (index published).
3. Ground-water stations reported by Federal (as of July 1967) and non-Federal agencies.
4. Areal investigations and miscellaneous investigations reported by Federal and non-Federal agencies.

Information on water data acquisition at stations is reported only for those sites where data have been or will be obtained for three or more years. Maps showing locations of surface-water and water-quality stations included in the 1967 edition of the catalog are published and are available.

Water-data storage system

Figures of daily discharge collected by the U.S. Geological Survey at regular streamflow stations for about 165,000 station years of record are stored on a set of 24 magnetic tapes. This covers more than half of all the streamflow data collected by the Geological Survey in cooperation with State, municipal, and other agencies. The data are stored in discrete units of daily figures for water discharge from each gaging station for each month; thus, the data are compatible with a variety of statistical programs for analysis on the basis of calendar years, water years, climatic years, or any other desired time period.

An automated system of storage and retrieval of surface-water-quality data has been used since October 1959. All data collected since then have been entered into the system, within which they have been separated into five basic groups:

1. Surface-water chemical and physical analyses
2. Suspended sediment
3. Water temperature
4. Specific conductance
5. Multi-item data collected by digital monitors.

The Geological Survey has coded data in machine form for about 25,000 ground-water wells and for about 15,000 chemical analyses of water from these wells. The file, which uses the latitude-longitude system for locating wells, includes information relative to State, county, use of water, use of well, depth, drilling method, drilling date, yield, water levels, physiographic data, aquifers, lithology, and when available, quality-of-water data.
URBAN HYDROLOGY

W. J. Schneider reported that a contract study by the Urban Hydrology Research Council of the American Society of Civil Engineers for the Water Resources Division of the U.S. Geological Survey has been completed. The study identifies the needs for hydrologic data in the urban environment and recommends a program for collection of these data as part of an overall water-management plan for urban areas. Three task groups composed of recognized experts in urban hydrology from all segments of the engineering profession identified basic data needs, appraised existing capabilities for collection of these data, and recommended installation of networks for the collection of these data.

Studies of urban runoff and floods

In studies of urban runoff in Houston, Tex., S. L. Johnson found that unit hydrographs for many small basins in the area appear to be nonlinear. Generally, the unit-hydrograph peak derived from extreme storms is consistently larger than the linearly derived unit-hydrograph peak. However, in the Houston area, many unit-hydrograph peaks derived from larger storms are less than unit-hydrograph peaks derived from smaller storms. The phenomenon is being studied further. In the studies of the effects of urban development on floods in northern Virginia, D. G. Anderson concludes that lag time appears to be the parameter most affected by urbanization. The lag time for a completely storm-sewered system is about one-eighth that of a comparable natural system, while lag time for basins in which tributaries only are storm-sewered is about one-fifth that of a comparable system. Flood peaks are also affected. On small steep basins, drainage improvement alone may triple the size of average flood peaks, and complete development of stream channels and basin surface may cause an eightfold increase in the size of average flood peaks. However, for less-frequent floods (those with recurrence intervals of about 50 years), the ratio of increase in size of peak is only about half that of the average flood.

Substantial effects of urbanization on flood peaks were found by L. A. Martens in Charlotte, N.C. The completion of the first phase of the study resulted in the development of a formula for peak runoff which takes into account the degree of imperviousness of the basin. As a result, flood peaks for drainage areas of more than 5 sq mi can be determined for various degrees of urbanization for recurrence intervals up to 50 years. The second phase of the project will extend the results of the first phase to smaller drainage areas of less than 5 sq mi. Instrumentation has been installed, and data are now being collected.

In studies of East Meadow Brook on Long Island, N.Y., G. E. Seaburn reports that average annual direct runoff increased 270 percent between 1937 and 1962 while the amount of land in the basin drained by storm sewers increased 570 percent. The average peak discharge of a 1-hour unit-hydrograph increased about 2.5 times and the widths of the unit-hydrograph, W_50 and W_75, decreased 38 and 28 percent, respectively. Analyses of rainfall-runoff data showed that direct runoff during an urban period (1964-66) was 1.5 to 4.0 times greater than the direct runoff for the pre-urban period (1937-43). G. E. Seaburn also reports that results of preliminary studies at two recharge basins on Long Island, N.Y., show that the average ratio of runoff to rainfall was 10 percent at the Syosset basin and 14 percent at the Westbury basin. The estimated average annual ground-water recharge from runoff to the basin in 1967 was 10 acre-feet and 7.5 acre-feet for the Syosset and Westbury basins, respectively. The average infiltration rates at the Westbury basin for 12 storms during 1967 was 211 gpd per sq ft.

Consideration of water resources in selecting landfill sites in Florida

A preliminary study of a 600-sq-mi area in northern Hillsborough County, Fla., indicates that about a third of the area is suitable for sanitary landfill sites. J. W. Stewart and R. V. Hanan report that the most favorable locations generally would be in the less developed eastern half of the area. The most unfavorable sites for placement of landfills would be in areas affected by large-scale withdrawals from the Floridan aquifer where contamination of the aquifer can occur locally by downward infiltration from the shallow water table; in or adjacent to areas of sinkhole collapse which may be directly or indirectly connected with the aquifer, that is, where water can move rapidly underground; and along the Hillsborough River and other streams where the bottoms of the stream channels intersect the top of the limestone aquifer. The most suitable locations generally would be in the less developed eastern half of the area south of the Hillsborough River. The most unfavorable sites for placement of landfills would be in areas affected by large-scale withdrawals from the Floridan aquifer where contamination of the aquifer can occur locally by downward infiltration from the shallow water table; in or adjacent to areas of sinkhole collapse which may be directly or indirectly connected with the aquifer, that is, where water can move rapidly underground; and along the Hillsborough River and other streams where the bottoms of the stream channels intersect the top of the limestone aquifer.

Urban water-resources studies of two areas in Florida

Recent studies on the water resources of Broward County, Fla., by C. B. Sherwood, H. J. McCoy, and C. F. Galliher indicate that ground-water supplies are available to meet demands of a mushrooming popula-

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40 Seaburn, G. E., in press. Effects of urban development on direct runoff to East Meadow Brook, Nassau County, Long Island, New York: U.S. Geol. Survey Prof. Paper 627-B.
tion. However, potential problems of water quality are increasing because of the lag in the development of water supplies and sewage treatment facilities. Coastal ground-water supplies are replenished by infiltration from controlled canals of the regional water management system. The canals receive large quantities of treated sewage effluent and other manmade contaminants which tend to build up during dry seasons. Other natural and manmade water problems are being overcome through effective water management. Data indicate that management practices have been effective in preventing major flooding during hurricane seasons and in preventing the further intrusion of salt water into the Biscayne aquifer during droughts. Current studies indicate that replenishment in major well-field areas may be improved appreciably by minor modifications in the system of fresh-water canals.

A new study to monitor the effects of urbanization in Florida is reported by H. G. Stangland, Jr. Instrumentation has been installed to monitor the hydrologic system of a 27,600-acre area 16 miles southwest of Orlando. Development of the area will be intensive but controlled, affording opportunity to study changes in the hydrologic environment as the proposed three major centers of development progress. To date, 10 stream-flow stations, 19 shallow water-table observation wells, 4 deep-aquifer observation wells, and 4 rain gauges have been installed to measure the inflow and outflow of the area. Water-quality samples are also obtained at 9 key locations for laboratory analyses. Analyses are also being made for pesticides.

Flood plains and artificial lakes as urban water-management problems

A study by A. M. Spieker of Salt Creek basin, a small watershed in suburban Chicago, showed water management to be an integral part of urban comprehensive planning. Especially important to planning in this basin are flood-plain management, improvement of water quality, and preservation of ground-water recharge areas. Spieker found that open-space preservation, landscaping and controlled commercial and industrial development are effective means of flood-plain management. Fills, refuse disposal sites, and uncontrolled residential development of flood plains, on the other hand, tend to have harmful results. Preserving open space adjacent to the stream has the multiple benefits of flood-plain management, preserving ground-water recharge areas, and providing needed recreation space. The low flow of Salt Creek has increased as the basin has become more urbanized, as a result of increased effluent from sewage treatment plants.

A. M. Spieker is also conducting a survey of artificial lakes in urban developments. Preliminary results indicate that unless these lakes are carefully planned, constructed, and maintained, many problems result from their use. Both surface-water lakes formed by impoundments and water-table lakes formed by excavation are affected. Sediment problems occur when land is laid bare during urban construction; growths of algae are caused by enrichment of the lake with nitrates and phosphates from lawn fertilizers, from septic tank effluent, and from overflows of combined sewers. Mud flats and other shoreline maintenance problems result from fluctuating lake levels.

Importance of interpreting hydrologic data for urban planning

Emphasis on interpretation of hydrologic data for utilization in urban planning is being studied by F. T. Hidaka and B. L. Foxworthy for the Seattle-Tacoma, Wash., metropolitan area. Decisions as to the kinds of data to be collected and types of interpretations to be made are being formulated through discussions involving city, county, and regional planning agencies. Emphasis is being placed on translating standard hydrologic data into documents of direct use to planners. Hidaka and Foxworthy have concluded to date that to be of most benefit in guiding urban development, urban hydrology must be largely predictive and must analyze future local changes within a changing regional hydrologic system affected by urban patterns.

WATER USE

Water use in the United States

A report by C. R. Murray (R0417) on water use in the United States in 1965 indicated that a 15-percent increase in off-channel water use took place from 1960 to 1965. This resulted in an average of 310 bgd being withdrawn in the latter year for public supply, rural domestic and livestock, irrigation, and industrial use; that is, 1,600 gpd per capita. About 75 percent of the total industrial water was used in 1965 for cooling purposes in thermoelectric power plants, where fresh-water use since 1960 increased about 25 percent and saline water 33 percent. Hydroelectric withdrawals, a within-channel, nonconsumptive use, increased 15 percent to 2,300 bgd in 1965. Water actually consumed averaged 78 bgd, a 28 percent increase in 5 years. Ground water supplied 61 bgd (0.5 bgd saline) and surface water 250 bgd (44 bgd saline) for off-channel use. Reclaimed sewage supplied 3 2 bgd to irrigation and industry. The average annual U.S. streamflow is about 1,200 bgd, 4 times the off-channel use and 15 times the consumption. However, the estimated dependable
fresh-water supply is less than half the total runoff, and in many river basins, water must be withdrawn repeatedly; in some basins, more than half the dependable supply is consumed. Water-use data were tabulated by States, water-use regions, and by Water Resources Council regions.

Water use for public supplies in Maryland

J. D. Thomas and S. G. Heidel (r 1162) report that the 65 largest public water supplies in Maryland delivered about 378 mgd to over 3 million people. The two largest supplies are the Baltimore Bureau of Water Supply and the Washington Suburban Sanitary Commission. These supply about 320 mgd to 2,444,000 people (about 70 percent of Maryland's population in 1965). Baltimore's water supply comes chiefly from Gunpowder Falls and the North Branch Patapsco River; a supplemental supply is available from the Susquehanna River. Most of the water provided by the Washington Suburban Sanitary Commission comes from the Potomac and Patuxent Rivers.

Sixteen municipal supplies use surface water, 43 use ground water, and 6 use both surface and ground water. Surface water serves more than 80 percent of the population, although more individual communities obtain their supplies from ground water. Quality of the water delivered is generally good, and treated water of most municipalities is soft or moderately hard. Twenty-two public supplies are reported to add fluoride, and 10 supplies have natural fluoridation of 0.4 ppm or more.

Estimated water use in Nevada, 1950–65

J. R. Harrill and G. F. Worts, Jr. (r2014) report that from 1950 to 1965 the population of Nevada increased from about 150,000 to 472,000 and that concurrently the withdrawal of water from streams and ground water increased from about 1,610 mgd to 2,050 mgd (93 percent of the latter was for irrigation). Because of limitations of supply, surface-water use increased only from 1,430 mgd to 1,610 mgd during this period, whereas ground-water use (spring flow and pumpage from wells) increased almost threefold—from 170 mgd to 483 mgd. More than half the latter increase occurred during the last 5-year period (1960–65). Although spring flow since 1950 has supplied a nearly constant 115 mgd, pumpage of ground water from wells for irrigation increased from about 27 mgd in 1950 to 259 mgd in 1965. Pumpage of ground water for all purposes doubled for the period 1950–55, 1955–60, and increased 60 percent from 1960–65 (the latter represents an average increase of 27 mgd). Additional increased demands probably will be provided by ground water and by increased diversions made possible by future Colorado River developments. During the period 1960–65, ground-water use increased as follows: irrigation, 37 percent; public supply, 40 percent; industrial self-supplied, 100 percent; and rural use, 60 percent.

Water used (in million gallons per day) by category and source of supply in 1965 was as follows: irrigation, 360 ground water and 1,550 surface water; public supplies, 60 ground water and 37.5 surface water; industrial self-supplied, 36 ground water and 26 surface water; and rural, 14.3 ground water and 3.3 surface water.

The Humboldt River basin furnished the largest quantity of surface water in 1965 in Nevada (34 percent of the State total). Elko County, which includes the headwaters of the Humboldt River, led other Nevada counties in surface-water withdrawals (also 34 percent of the State total). Large ground-water withdrawals were made in the central region (26 percent of the total State withdrawals and the Colorado River basin (35 percent). Clark County, in the Colorado River basin, and Humboldt County, in the Humboldt River basin and the Black Rock Desert region, led all Nevada counties in ground-water withdrawals with 20 percent and 19 percent, respectively, of total State ground-water withdrawals. These quantities were more than double those of any of the other counties.

Water use in Tennessee

A report by A. M. F. Johnson, J. M. Wilson, and H. B. Nicols (r0015) indicated that agricultural uses of water in Tennessee in 1964 were as follows: 11.4 billion gallons (an average of 31.1 mgd) for watering livestock, 3.1 billion gallons (8.5 mgd) for irrigation, and 30 million gallons (0.08 mgd) for washing vegetables. The data on water use for irrigation is tabulated by counties and by river basins (Cumberland, Tennessee, and lower Mississippi). Total irrigated acreage in Tennessee in 1964 (19,632 acres) was 56 percent less than in 1958, chiefly due to the abundance of rainfall in 1964 compared with 1958. Irrigated land was divided in the three river basins as follows: Cumberland 3,662 acres, Tennessee 10,751, and lower Mississippi 5,219. In Tennessee in 1964 there were 706 irrigation systems in operation—79 using ground water, 484 streamflow, and 143 ponds.

The report relates precipitation in Tennessee for 1964 with water used for irrigation, and gives a summary of water law as pertaining to water use.

Part B of the report, which summarizes industrial water use in 1964 in Tennessee, is now in preparation. Five principal types of data are given—how much water was withdrawn, from what sources, for what pur-
northern part of the city. Adequate supplies are available for additional development, but well locations should be selected to avoid excessive lowering of the piezometric surface.

MARINE GEOLOGY AND HYDROLOGY

MARINE GEOLOGY

The Nation's submerged continental margin includes an area of more than 1 million sq mi. Knowledge of the geology and mineral resources of this area is required if the Nation is to meet increasing demands for minerals and fuels.

Particular attention must be given to the study of geologic processes that shape and modify our coasts and govern man's use of these regions. Increasing concentration of population along the coasts has increased the need for geologic knowledge to aid in planning land use and to aid in assessing potential geologic hazards to construction and urban development.

To meet these needs, the U.S. Geological Survey is continuing its program of geologic, geophysical, and hydrologic analyses of the continental margins of the United States, including bays and estuaries. These analyses are depicted on maps at various scales: (1) reconnaissance maps at a scale of 1:1,000,000 or smaller; (2) intermediate-scale maps at 1:250,000 of the areas that have promise for new sources of minerals; (3) detailed maps at scales of 1:62,500 or larger for studies of geologic processes in selected areas that have high economic potential or special scientific significance, or that are subject to hazards of immediate local impact.

Marine geologic and hydrologic investigations are being conducted by the Geological Survey on the Atlantic, Gulf of Mexico, Pacific, and Alaskan continental margins. Some of the investigations are being conducted under research contracts with universities and oceanographic institutions, and others are conducted under cooperative arrangements with such Federal agencies as the Coast and Geodetic Survey, Bureau of Commercial Fisheries, and the Naval Oceanographic Office. Results of the past year's research programs in marine geology and hydrology are summarized below.

ATLANTIC CONTINENTAL MARGIN

A reconnaissance of the geology and mineral resources of the Continental Shelf and slope is nearing completion, and more detailed geologic and geophysical
studied in the few areas of coastal New England that it underlies. Seismic refraction studies by R. N. Oldale (p. B122-B127) distinguished two rock layers above basement along the coast of southeastern Massachusetts. The layers are composed of sediments of Late Cretaceous to Holocene age, with seismic velocities of 1.5 to 2.4 km/sec. A compilation of buried basement topography along the south coast of New England and in the Gulf of Maine shows a close correlation to present drainage systems on land.

Preliminary interpretation by Elazar Uchupi (WHOI) of seismic profiles and magnetometer records from the New England seamounts indicated that the seamounts are probably of pre-Cretaceous age. Mytilus Seamount appears to have had a flat top during a former epoch; its acoustically transparent cap approximately 300 m thick atop the former erosional surface is probably an organic reef of Eocene age.

A digitally controlled precision graphic recorder system was developed and constructed by K. E. Prada (WHOI). This represents a significant advance in the techniques in digital integrated circuits and precision-stepping motors.

**Experimental giant corer**

C. D. Hollister (WHOI) constructed and began field-testing a device designed to obtain considerably longer cores than can be obtained with conventional piston-corers, which are generally limited to 30 m or less. The longer cores would fill a gap between conventional piston cores and ocean-bottom drill cores. The new device is designed for a total loading of 16,100 lb.

**New curve of sea-level position**

More than 80 radiocarbon dates on samples from the Atlantic Continental Shelf of the United States were used by J. D. Milliman and K. O. Emery (both of WHOI) to construct a new sea-level curve of the past 35,000 years in that region. Sea level 30,000 to 35,000 years ago was near the present position, but the Wisconsin regression lowered it to about -130 m 16,000 years ago. Postglacial transgression began about 14,000 years ago, but its rate decreased markedly about 7,000 years ago.

**Carolina Continental Shelf geology**

Geologic mapping of the Continental Shelf off North and South Carolina under a research contract with Duke University was continued by O. H. Pilkey, who discovered active wave-erosion channels at the surprisingly great depth of 60 feet. Sand is moving seaward across the shelf only at the points of current convergence marked by the position of the coastal capes. A newly found series of reefs on the Carolina
Gulf of Mexico and Caribbean Sea

The Gulf of Mexico-Caribbean area was the scene of three significant advances in marine geology: in Project TEKTITE I a scientific team that included a geologist lived and worked beneath the ocean for 60 days; in a new U.S. Geological Survey-Navy program, one of the world's largest sparker seismic systems gave outstanding results from the first part of a comprehensive geologic investigation; and in the JOIDES (Joint Oceanographic Institutions Deep Earth Sampling Committee) Deep Sea Drilling Project the presence of oil and gas beneath the deep sea was demonstrated for the first time. Other investigations include exploration of the structure of Mona Passage west of Puerto Rico and of the Continental Shelf and slope off southeastern Puerto Rico, and the application of a variety of techniques to study the Continental Shelf from Florida to Texas.

Project TEKTITE I

Four geologists from the U.S. Geological Survey participated in Project TEKTITE I, an experiment designed to measure man's ability to conduct scientific research on the sea floor over an extended period of time. The project, concluded on April 15, 1969, demonstrated that man can conduct effective research from an underwater habitat and that saturation diving techniques hold promise for future geologic exploration of the sea floor. The project was carried out cooperatively by the U.S. Department of the Interior, U.S. Navy, National Aeronautics and Space Administration, and the General Electric Co.

E. H. Clifton, with three biological oceanographers from the U.S. Bureau of Commercial Fisheries, spent 60 days living and working in a habitat on the bottom of Lameshur Bay, St. John, V.I. R. L. Phillips extended the geologic studies into areas inaccessible to the habitat-based aquanauts. J. I. Tracey, Jr., and Gilbert Corwin assisted with base-map construction prior to the dive and examined onshore and nearshore geologic features during the experiment.

Geologic studies included compilation by Clifton of a detailed map that delineates bottom-sediment types over the area within swimming range (about 1,000 feet) of the habitat and preparation by Phillips of a more general map showing bottom-sediment types along the southeast coast of St. John. Clifton also studied rates of reworking on organisms on sand flats adjacent to coral reefs in the vicinity of the habitat and found that the upper layer of sediment is completely reworked in only a few days. Artificially constructed ridges comparable to sand ripples were obliterated by organisms within a week. Studies also showed that empty pelecypod valves in the low-energy reef environment generally lie concave side upward, a distinctly different orientation than that formed by wave and current activity along a high-energy coast; such differences may be useful for identifying ancient depositional environments. The orientation pattern of gorgonids and milliporids living on the reef differs slightly but distinctly from the dominant linear spur-and-groove patterns of the reef, suggesting that the dominant reef patterns are either relict or form during abnormal environmental conditions. Studies conducted jointly with the biologist-aquanauts on growth rates of the green algae Penecills and Eudotea should permit estimates of the contribution of aragonite needles to the sediment by these plants. Phillips, while mapping offshore on the south side of the island, located an extensive fossil beachrock that indicates a stillstand of the sea 20 to 25 feet below the present sea surface.

Joint U.S. Geological Survey-Navy study of Gulf of Mexico

The Geological Survey and the U.S. Naval Oceanographic Office cooperated in a study of the geophysics, bottom sediments, and hydrography of the Gulf of Mexico. Over 15,000 traverse miles of seismic profiling and magnetic and gravity measurements were obtained during three cruises of the USNS Kane. A 160,000-joule sparker seismic system was in operation 97 percent of the time at sea, and depth penetration was in the range 3.8 to 4.7 sec, corresponding to as much as 24,000 feet of sediment. Deep reflectors were traced across the western half of the basin. Diapiric material underlies much of the basin and appears to have influenced the tectonics of the western Gulf since Mesozoic time. It is concluded that most of the western Gulf has potential for oil and gas. Geological Survey participants in the study are H. L. Berryhill, Jr., L. E. Garrison, H. R. Hill, J. W. Lee, M. S. Marlow, R. A. Patrick, D. W. Scholl, and A. R. Tagg.

Participation in JOIDES Deep Sea Drilling Project

J. D. Bukry participated in the JOIDES (Joint Oceanographic Institutions Deep Earth Sampling Committee) Deep Sea Drilling Project aboard the Glomar Challenger, managed by Scripps Institution of Oceanography and sponsored by the National Science Foundation. Drilling in the Gulf of Mexico and the North Atlantic was in water depths from 2,827 to 5,254 m. Seven drill sites represent 3 geologic settings: the deep basin of the Gulf of Mexico, the Hatteras abyssal plain, and the Bermuda Rise. Sediments of Late Jurassic-
sic to Quaternary age were recovered from subbottom depths as great as 771 m. Bukry dated calcareous nanofossils on board as a guide to further drilling. The virtual omnipresence of coccoliths in oceanic sediments of all ages from Jurassic to Holocene, and the speed with which they could be dated, made them the most valuable fossil group for guiding shipboard drilling operations.

Results of the drilling included discovery that the Sigsbee Knolls in the deeper part of the Gulf of Mexico contain oil and gas and are similar to the salt domes in the producing area of the Gulf. Four holes east of the Bahama platform proved that seismic horizon Beta lies at the top of Upper Cretaceous chert, beneath which are semiconsolidated Upper Jurassic pelagic sediments containing coccoliths and radiolarians. On the Bermuda Rise, sufficiently far above the Hatteras abyssal plain that turbidites were not expected, Eocene mud-pebble conglomerates and chert-bearing turbidite beds were cored. The occurrence of widespread turbidite beds on an oceanic rise indicates that an active oceanic crust has produced a varied ocean-floor geology.

**Geology of the Puerto Rico Continental Shelf**

The second annual cruise by the Geological Survey in cooperation with the Industrial Development Administration of Puerto Rico, under the leadership of L. E. Garrison, extended reconnaissance knowledge of geology and potential mineral resources over much of Mona Passage. Continuity of a major fault from Puerto Rico to the northeastern coast of Hispaniola was established. A sample of beach rock dredged from deeper than 200 m in Mona Passage substantiated previous indications of subsidence there. Dredging on Grappler Bank southeast of Puerto Rico yielded volcanic rock similar to that mapped on Puerto Rico. Acoustical profiles along the shelf and slope of south-central Puerto Rico show a number of northeast-trending faults not previously known. An east-trending fault was also discovered on the slope, and the major northwest-trending transcurrent fault that traverses southwestern Puerto Rico was shown to extend off the southeast coast. The general structural pattern recorded is favorable for oil and gas exploration. Use of a chartered 30-m vessel showed the advantages of catamarans as seagoing research platforms.

**Gulf of Mexico Continental Shelf**

A. H. Bouma (Texas A&M University) found appreciable concentrations of zircon and ilmenite in an area east of Ship Shoal on the Louisiana Continental Shelf. Zirconium concentrations exceed 0.35 percent, and associated titanium concentrations reach 0.4 percent. Off the Texas coast, seismic reflection profiles indicate the presence of a large buried delta beneath the Continental Shelf seaward of the Brazos River. By contrast, no such delta appears seaward of the mouth of the Rio Grande.

**Geochemical maps of the Gulf of Mexico shelf**

A series of maps prepared by C. W. Holmes shows the distribution of 22 metals and trace elements in the surficial sediments of the Continental Shelf from southern Florida to the Mexican border. The maps were based on 1,500 samples collected by the Galveston station of the U.S. Bureau of Commercial Fisheries, and by the Geological Survey. Relation of the deposits to sediment movement and to sea-floor topography is depicted. Lead is concentrated in an area seaward of the Mississippi River and Galveston Bay, probably representing pollution by industrial wastes. Zirconium in concentrations as great as 1,000 ppm was found in several samples in linear patterns that are suggestive of beach ridges.

**Texas barrier island studies**

K. A. Dickinson and C. W. Holmes distinguished sands of different origin on the basis of modal size in a detailed study of a portion of Padre Island south of Corpus Christi, Tex. Coarse-grained sand from a northern source overlies finer-grained sand from the south, indicating a recent change in longshore transport direction. The entire barrier sand body, about 60 feet thick, overlies lagoonal sediments. Comparative studies of a sequence of aerial photographs show that the western part of the barrier island has migrated about 1,000 feet westward into Laguna Madre since 1948. Geochemical maps of the lagoon show that the chemistry of the water-sediment interface is controlled by the wind, which is the major dynamic influence in the lagoon.

These studies utilized color and infrared photograpy and infrared imagery provided by the National Aeronautics and Space Administration. H. L. Berryhill, Jr., is appraising their value in the portrayal of bottom topography and sediment.

**Organic geochemistry of modern sediments**

Along the northeastern coast of the Gulf of Mexico, organic constituents of the sediments forming in estuarine environments were found to differ from those forming in tidal flats. J. G. Palacas, V. E. Swanson, and others report that about 50 percent of tetrabutyl bitumen in the estuarine muds of Choctawhatchee Bay, Fla., is composed of hydrocarbons, compared with only about
23 percent in the nearshore sands of the estuary. By contrast, in the muds of the tidal marsh environment of Apalachee Bay, 20 percent of the bitumen is hydrocarbon, compared with 40 percent in the sands offshore. Interpretation of these findings and their possible relation to the formation of oil and gas deposits is under study.

**PACIFIC CONTINENTAL MARGIN**

Marine geologic studies of the Continental Shelf and Slope off the Pacific coast, are directed toward three principal goals: (1) assessment of geologic hazards that affect urban and shoreline development; (2) evaluation of mineral resources, and (3) determination of the basic geologic structure of the region. Universities participating in these investigations include the University of Washington, Oregon State University, University of Oregon, Stanford University, University of Southern California, and Scripps Institution of Oceanography (SIO) of the University of California at San Diego.

**San Francisco Bay**

D. S. McCulloch and P. R. Carlson used low-frequency (sparker) and intermediate-frequency (boomer) sound sources simultaneously in subbottom seismic profiling in San Francisco Bay and adjoining San Pablo and Suisun Bays. A map showing depth of the buried bedrock surface beneath these bays is in preparation. Two high-angle faults appear to cut unconsolidated sediments and extend upward to the present bay floor. Distinctive acoustic reflectors at depths as great as 150 feet were traced throughout the southern part of San Francisco Bay.

Geochemical work by D. H. Peterson revealed that in general the winter distribution of dissolved silica in northern San Francisco Bay water is determined by the amount of fresh water discharged into the bay and by its subsequent dilution by sea water. Consequently, there is an approximately linear inverse correlation between dissolved silica and salinity. In summer, little dissolved silica is available because of the increased rate of utilization by phytoplankton and the decreased supply. Since the Sacramento River supplies about 900 tons of dissolved silica per day during the summer, diatoms are expected to be a significant part of the sediment deposited in San Francisco Bay.

**Structure of central California Continental Shelf**

A 13,000-joule multisource sparker system installed on the Geological Survey's 96-foot research vessel Polaris was used by G. E. Rusnak and S. C. Wolf to substantiate earlier work showing how the thick sediments of the Santa Barbara Channel thin out and abut against older crystalline or metasedimentary rocks off the Channel Islands. Records obtained from the outer side of the Channel Islands and seaward to the Patton escarpment show an acoustic basement with little or no sediment cover. North of Point Conception, a thick sequence of upper Tertiary sediments extends seaward from the Santa Maria basin across Santa Lucia Bank and down the continental slope, where irregular hummocky deposits suggest downslope slumping. The acoustic basement was traced from north of San Luis Obispo to north of Monterey.

**Continental-margin tectonics**

New evidence that rocks of the Gorda Basin off northern California are interacting with those of the adjacent continental margin is reported by E. A. Silver (SIO) and G. W. Moore. Magnetic evidence suggests that basement rock at the north end of the Gorda Basin is moving under the continental margin as the basin turns clockwise. The Gorda Basin seems to be a small tectonic plate that is caught between the large Pacific and North American plates and serves as a partial obstacle to their relative movement. Acoustic profiles near the landward edge of the Gorda Basin show a layer of sediment over a basement that is presumed to be basaltic and the source of the magnetic anomalies, while a similar folded and faulted layer of sediment occupies an elevated position on the continental slope. As the basin rotates, the sediment is believed to slide over the basalt, and the underthrusting basalt compresses the sediment against the continental margin and thereby uplifts it.

Moore also participated in Scripps Institution of Oceanography Expedition Scan, which is determining sites in the Pacific to be cored by the drilling vessel Glomar Challenger in the JOIDES Deep Sea Drilling Program. The expedition investigated seven potential drilling sites nearest to the Pacific coast of the United States. Using satellite navigation, an area 75 km square around each site was studied to determine submarine topography, subbottom reflectors, and magnetic pattern. Precise position of proposed drilling was selected, and bottom photographs, a piston core, and a heat-flow measurement were obtained at the site.

**Gold on the northern California shelf**

A joint investigation by G. W. Moore (USGS) and E. A. Silver (SIO) shows that the background gold content of surface sediment on the Continental Shelf between Bandon, Oreg., and Eureka, Calif., is about 1 ppb. Four anomalous tracts ranging in extent from 10 to 30 sq km have gold values above 10 ppb, and the richest sample contains 390 ppb. The anomalous area
seem to lack a close correlation with water depth, but they are related to areas underlain by soft Cenozoic strata that contain small quantities of dispersed gold originally derived from lode deposits in the Klamath Mountains. This relationship suggests that the offshore gold accumulations are lag concentrates produced from the Cenozoic deposits by wave erosion during the post-glacial rise in sea level. Gold content of surface samples is too low for economic recovery. Drilling will be required to determine whether the anomalous areas are underlain by higher grade material.

**Geologic mapping of northern California continental margin**

An area about 6 degrees on each side (130,000 sq mi) of the continental margin off northern California was geologically mapped at reconnaissance scale by G. W. Moore, working jointly with members of the Scripps Institution of Oceanography. Techniques of investigation include continuous seismic profiling with an air-gun source, rock dredging, and bottom photography. Eocene sediments crop out on the sea floor and have been photographed at the top of the continental slope. A prism of sediment as much as 1,500 m thick of probable late Cenozoic age lies at the foot of the slope. This sediment prism thins seaward and ultimately wedges out near the crest of the Gorda Ridge.

**Oregon Continental Shelf geology**

A map of the Oregon Continental Shelf from Cape Blanco to Coos Bay showing the areal distribution of seismic units and structural features defined by sparker profiling was completed by L. D. Kulm, G. A. Fowler, and others (Oregon State University), in cooperation with the U.S. Geological Survey. A preliminary geologic map of the shelf from Cape Blanco south to the California line was also prepared. The units were tentatively correlated with stratigraphic units onshore. Several basins containing gently folded strata of probable Miocene to Pliocene age occur on the shelf. The largest three of these occur northwest of Coos Bay, in the area between Cape Blanco and Coquille Bank, and southwest of Cape Sebastian. Unconformities with slight angular discordance separate the strata into at least seven subunits in the Cape Blanco-Coquille Bank area. Extensive areas underlain by moderately folded and faulted strata of probably older Tertiary age occur offshore between Coos Bay and Bandon. From the California line north to Cape Blanco, more highly deformed and acoustically nonreflective rocks of probable Mesozoic age form the sea floor for varying distances offshore and probably are correlative with onshore Jurassic and Cretaceous rocks.

Helicopter reconnaissance by H. E. Clifton, R. E. Hunter, and R. L. Phillips shows that some sea stacks off the southern Oregon coast are composed of gently folded sandstone closely resembling and probably correlative with Upper Cretaceous sandstone onshore. The sandstone is relatively rich in quartz, low in detrital matrix content, commonly fairly porous, and has sedimentary structures suggestive of both shallow marine and proximal turbidite origin. The offshore occurrences, together with those onshore, suggest that Upper Cretaceous strata may be widely distributed on the Oregon Continental Shelf and are potential reservoir rocks for petroleum accumulation.

**Surf zone of Oregon beaches**

Scuba observations by H. E. Clifton, R. L. Phillips, and others suggest that the inshore or shore-face zone along southern Oregon sandy beaches can be divided into several subzones, each characterized by a distinctive assemblage of sedimentary structures. The zonation varies somewhat with changing wave conditions. The principal features can be recognized over a wide range of summer wave conditions in both sheltered and open locations. The beaches studied are characterized by a shore-face terrace whose step is located beneath the zone in which the normal waves begin to steepen noticeably, and in which the larger waves break. Seaward of the shore-face terrace step, the dominant sedimentary structure is small-scale ripples having wave lengths of 3 to 8 inches and no pronounced or permanent asymmetry. As the step is approached, the ripples become larger and more asymmetric, with steep slopes facing landward. Immediately shoreward of the terrace step is a zone having a relatively planar surface. In this zone, transitory ripples are leveled by each passing wave surge. These studies are directed toward an understanding of the formation of black sand deposits.

**Origin of Oregon coastal terraces**

Studies by R. J. Janda in the area of four 1-road terrace platforms underlying the stepped coastal plain near Cape Blanco indicate that the platforms were cut during marine transgressions; however, most of the sediment on these platforms was deposited during regressions. The upper Tertiary and Pleistocene marine rocks in this same area attest to continuous uplift since at least late Miocene time. Thus the most probable cause of the alternating transgressions and regressions during the Quaternary is a combination of glacio-eustatic oscillations of sea level and upward tectonic movement.
Washington Continental Shelf

Several elongate areas of bottom sediment that contains high concentrations of heavy minerals were located on the Washington Continental Shelf by D. A. McManus and others (University of Washington). Preliminary results indicate a low gold content. Seventy-five percent of samples of unconsolidated bottom sediment contain less than 1 ppb Au but mineralogical and heavy-metal analysis is not complete, and the overall economic significance of the concentrations is not yet known.

Preliminary examination of continuous seismic profiles in the same area of the Washington shelf, north of the latitude of Grays Harbor, indicates that the rocks beneath the shelf are structurally complex; numerous faults and folds as well as penetration structures appear on the profiles.

ALASKAN CONTINENTAL MARGIN

The Continental Shelf adjacent to the Alaskan coast is the largest segment of the Nation's Continental Shelf that remains to be geologically explored. Preliminary studies indicate that it may contain petroleum and natural gas resources as well as deposits of detrital heavy minerals such as gold, tin, and platinum. Areas of localization of these resources are being investigated in the Bering Sea and the northern part of the Gulf of Alaska. Bering Sea studies are also providing information both on the tectonic evolution of the westernmost part of North America and on unexpected and extensive glacial deposits that originated in Siberia. Studies of the Gulf of Alaska are contributing to the knowledge of large sedimentary basins and of sedimentary processes in fiords. Cooperating Federal agencies and contracting universities include the U.S. Coast and Geodetic Survey, the University of Alaska, and the University of Washington.

Bering Sea investigation

D. M. Hopkins and others continued a study of the geology of the northern Bering Sea with emphasis on resource potential in cooperation with the U.S. Coast and Geodetic Survey and the University of Washington. A. R. Tagg and H. G. Greene investigated possible gold targets along 80 miles of the coast of Seward Peninsula, using continuous seismic profiles. The locations of former stream channels and glacial moraines over a broad region in the northern Bering Sea were delineated by Muriel Grim and D. A. McManus. (both University of Washington).

The distribution of gold in surface sediments was studied by C. H. Nelson and Hopkins from about 300 bottom samples obtained in the vicinity of Nome and another 300 samples from elsewhere in the Bering Sea. Relatively coarse gold is present in coarse relict gravel in the northern Bering Sea. A minable "skin" deposit of richly auriferous wave-handled gravel seems to be present over gold-bearing glacial drift near Nome. Promising surface concentrations were also found in samples from the vicinity of Sledge Island and in an area between Cape Rodney and Cape Wooley. In the latter area, reconnaissance sampling indicates an offshore area of relative gold concentration where no significant onshore placers are known. The coarse gold offshore may be related to local mineralization in bedrock exposures far offshore at shallow depths. Small quantities of fine gold are widely dispersed in the mud and muddy sand that form the predominant bottom sediments of the northern Bering Sea. Statistical analysis of regional variation in gold content of the samples points to the Seward Peninsula coast as the main source of the gold.

Geologic studies on St. Lawrence Island indicate that the northern and western shores of the island were overridden by ice that probably represented the outer part of a piedmont glacier whose area of origin lay to the north and west in the highlands of the Chukotsk Peninsula, northeastern Siberia. Onshore gravel and coarse bottom samples from several places offshore near St. Lawrence Island yielded shows of metal, including native copper and gold. The presence of native copper suggests the possibility of undiscovered Soviet copper deposits on the Chukotsk Peninsula.

As part of a U.S. Geological Survey-Environmental Science Services Administration Bering Sea cooperative project, the USC&GS Oceanographer and Surveyor gathered data for a bathymetric map of the northern Bering Sea. C. H. Nelson and others also carried out bottom sampling and seismic profiling operations aboard the Oceanographer.

Tin was found widely distributed in sediments of the Bering Strait-Cape Prince of Wales area by Nelson. Tin content was determined for approximately 60 samples collected aboard the T. G. Thompson (University of Washington), aboard the Oceanographer, and in part from an Eskimo skinboat. Tin was detected in most samples, and some were anomalously high in locations far from known land sources.

High-energy seismic profiles and magnetometer records interpreted by D. W. Scholl and D. M. Hopkins indicate that parts of the Bering Sea contain thick sediments that have a potential for petroleum. The seismic records have been placed on open file.
Gulf of Alaska investigations

R. E. von Huene and Erk Reimnitz (USGS) in cooperation with F. F. Wright (University of Alaska) studied bottom samples from Nuka Bay and Yakutat Bay. Gold was found only in traces in the fiords. It is thought to be concentrated on present beaches, on submerged beaches and banks, and locally in some glacial deposits. Seismic profiles between Gross Sound and Yakutat Bay revealed the outer limit of glacial moraines, which may locally be associated with accumulations of heavy minerals. Samples of late Tertiary age were dredged from Albatross Bank, where seismic information indicates a sediment thickness of 3 km. These findings suggest that the bank may be a potential source of petroleum.

OCEANIC ISLANDS

The geologic history and evolution of the continental margins is fundamentally related to the history and development of the deep-ocean floor. Much information on the geology of the deep oceans can be gained by geologic studies of oceanic islands as well as by geophysical investigations and drilling in the deep oceans. Studies of Hawaiian volcanism are described in another section of this report (p. A111). Investigations are also in progress off islands for which the United States has responsibility.

Geologic history of Midway Atoll

Clay mineralogy studies helped to reveal events that occurred when the volcanic core of Midway Island sank below sea level. Dorothy Carroll in examining cores obtained in 1965, found that a brown clay, largely allophane, resulted from subaerial weathering of the volcanic rocks prior to submersion. The overlying mixed-layer montmorillonite-chlorite developed in the gray reworked volcanic clays as a result of the change from swampy to marine conditions that developed as the volcano sank. The dominantly montmorillonite clay in the upper part of the sequence resulted from the addition of relatively abundant calcareous debris supplied by corals and other reef organisms that colonized the sinking volcano to form barrier reefs and finally the atoll.

Geology of the mid-Pacific mountains

Shallow-water fossils of Cretaceous age were previously obtained from two guyots of the deeply submerged Mid-Pacific Mountains that lie between the Marshall Islands and Hawaii. The area in which rocks of Cretaceous age are known to occur was extended toward Wake Island during a recent cruise by the research vessel Agassiz of the Scripps Institution of Oceanography in which H. S. Ladd (USGS) participated with W. A. Newman (SIO).

Seismic and echo-sounder surveying by the Agassiz proved that one of the guyots was actually an ancient atoll with its elevated rim now submerged more than 600 fathoms. Dredging on the atoll showed that its rim was built primarily by rudistids of Cretaceous age. Cretaceous corals were also obtained from the drowned atoll; some chert was present, and most of the dredged material was heavily encrusted with manganese oxide.

Holocene emergent reefs and dolomitization in the southern Line Islands

Perfectly preserved reef structures as much as 4 feet above present water level were found on Jarvis, Starbuck, and Malden Islands in the southern Line Islands (between Hawaii and Tahiti), by S. O. Schlanger (University of California at Riverside), and J. I. Tracey, Jr., who visited the islands aboard the U.S. Coast Guard vessel Planetree. The reefs occupy the area of former lagoons within the islands, and were protected from erosion by the island beach ridges. The emergent reefs show typical facies: massive coralline algal structures near the living outer reefs; coral-algal lagoon reef ridges; and, on Starbuck Island, shell-reef ridges, acres in extent, made up almost entirely of small, packed, articulated Tridacna.

The islands lie in the equatorial dry belt of the Central Pacific where rainfall is low and evaporation high. The central lagoonal areas are nearly filled sand flats slightly above sea level, containing hypersaline pools or ponds containing gypsum crusts. Short cores through the gypsum crust recovered lagoonal carbonate sediments.

A core from Jarvis Island was analyzed by Leigh Price (University of California at Riverside) and found to contain dolomite, calcite, and aragonite. A sample from this core about half a meter below sea level consisting predominately of dolomite was found by Meyer Rubin to have a C14 age of 2,530 ±250 years (W-2287). The dolomitization apparently followed the shoaling and emergence of the reef and resulted from evaporation of lagoonal water during the closing and filling of the lagoon.

APPRAISAL OF MARINE MINERAL RESOURCES

Active geological exploration for marine mineral deposits must be accompanied by overall appraisals of resources discovered to date, and by the best possible estimates of future potential. V. E. McKelvey, F. H. Wang, S. P. Schweinfurth, and W. C. Overstreet report that of the potential mineral resources of the United States continental margin, oil, gas, and natural
gas liquids have by far the greatest present and prospective value. Other materials now being mined offshore in United States waters include sulfur, oyster shell, sand, gravel, and salt. Except for salt, which is abundant in low-cost deposits on shore, there appear to be good opportunities for expanded future production of this other material. Also of prospective value in the near future are phosphorite deposits on the west coast, lime mud in the Gulf of Mexico, and gold in Alaskan waters. A variety of other heavy metals such as tin, chromium, and platinum on the continental shelves may have some potential for the more distant future. Large metalliferous ore bodies that are probably present within the bedrock of the Continental Shelf would be difficult to find, but within the reach of present extractive technology. Other minerals are also present in surficial or bedrock deposits—clayey, barite, tin, diatomaceous ooze, manganese oxide and associated metals, potash, and perhaps others (geothermal energy also is present)—but prospects for their development are further removed than for the others.


ESTUARINE AND COASTAL HYDROLOGY

Salt flux and salinity distribution in estuaries

The tidal reach of the Duwamish River of Washington approaches the ideal highly stratified or “salt-wedge” estuary. J. D. Stoner found that water from the salt wedge is entrained upward into the overriding surface layer, while only insignificant amounts of the fresher overlying water are mixed downward. The salinity of the water within the salt wedge varies little from the mouth of the river to near the tip of the wedge, whereas the salinity of the water near the surface increases progressively down the estuary. The net vertical entrainment varies linearly with fresh-water inflow, and it ranges from 0.013 cfs per longitudinal foot at 300 cfis fresh-water inflow to 0.026 cfs at 1,300 cfis fresh-water inflow. Calculated mean surface-layer salinities agree well with mean salinities determined in the field.

The distributions of salinity and velocity in the Duwamish estuary vary significantly with tidal movements and changes in the fresh-water inflow, according to J. P. Santos and J. B. McConnell. The upper boundary of the salt wedge is defined by a rather sharp decrease in salinity. Increases and decreases in the thickness of the salt wedge during tidal exchanges are accompanied by decreases and increases, respectively, in the thickness of the fresher upper layer. With increasing fresh-water inflow, the thickness of the salt wedge decreases and its upper boundary becomes more clearly defined. Average velocities through a cross section reach their maximum about two-thirds of the way through the tidal range and return to near zero at slack tide. At higher fresh-water inflows, ebb-tide velocities become larger and flood-tide velocities become smaller than at lower fresh-water inflows under similar tidal conditions.

For the Cape Fear River estuary of North Carolina, H. B. Wilder and E. F. Hubbard developed a series of curves for predicting the distribution of salinity at high tide during periods of low flow. Two curves (fresh-water inflow and height of high tide) are used to estimate the position of the 200-mg/l isochlor along the bottom of the river at high slack tide. These estimates are usually accurate to within 1 mile. The longitudinal distribution of saline water along the bottom of the channel, relative to a given concentration, tends to be constant for all high tides. When the estimated position of the 200-mg/l isochlor is used, the curves indicate the approximate relative position of any other chloride concentration from 200 to about 5,000 mg/L. Conversely, if the maximum chloride concentration during a given flood tide at a downstream point is known, the curves can indicate the maximum concentration at an upstream point during the same flood tide.

Sedimentation in estuaries

A summary of the status of knowledge of sedimentation in estuarine zones is being prepared in cooperation with the Federal Water Pollution Control Administration. Sources of sediments, their texture and composition, and the factors affecting their deposition are the topics of principal interest. The summary will serve as a basis for defining future programs for studying estuarine sedimentation. The existing knowledge of sources and deposition is being summarized by R. H. Meade from the available literature, and it is being extended by analysis of field data collected in several estuaries by the U.S. Army Corps of Engineers. The characteristics of bottom sediments of about 50 estuaries of the United States are being summarized by D. W.
In a study of the feasibility of converting Upper Tampa Bay, Fl., into a fresh-water lake, J. A. Mann computed that the inflow of fresh water (both surface and ground water) is about 160 mgd. The bay seems to be interconnected with the underlying aquifer system, and hence a fresh-water lake would act as a buffer against salt-water encroachment. The primary deterrents to freshening the bay, however, are the present level and the predicted future level of pollution.

**Underground water of the coastal zone and continental margin**

The concentration of salt in the pore fluid in strata beneath the Atlantic coastal region from Long Island, N.Y., to the Florida Keys was assessed by F. T. Manheim (USGS), in collaboration with M. K. Horn (Cities Service Oil Co.) (Manheim and Horn, 1940). Intercalated brackish and fresh water generally extends about 300 m below the land surface (or sea level, in the case of submarine aquifers), but reaches depths as great as 1,000 m in the South Carolina coastal region. Brine containing more than 100,000 ppm of salt is found in deeper strata in the Delaware-Maryland and Hatteras embayments and beneath Florida. S\textsuperscript{35} in the deep brine appears to be derived from evaporite of Jurassic and Early Cretaceous age.

Pore water was also studied in sediments beneath the northern continental slope of the Gulf of Mexico. F. T. Manheim, in collaboration with J. L. Bischoff (Woods Hole Oceanographic Institution) analyzed water squeezed from 18 cores drilled by the Shell Oil Co. Sediment penetration by the cores ranged from 35 to 300 m, mainly in Pleistocene and Holocene clays. Cores drilled near diapiric structures showed systematic increases in pore-water salinity with depth; salinity approached halite saturation, and one core actually penetrated salt. Samples taken from cores drilled away from diapiric structures showed little change in pore-water chemistry with depth. Therefore, appreciable increases in pore-water salinity appear to suggest diffusion from underlying salt plugs. The existence of shallow salt plugs may be detected by pore-water measurements in cores only a few meters long.

**MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS**

The Conservation Division of the U.S. Geological Survey is responsible for carrying out the Survey's role in the management of natural resources on Federal and Indian land. That role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of ...
the Federal and Indian lands, together with the lands of the Outer Continental Shelf (OCS). Primary functions are (1) mapping and evaluation of mineral lands, (2) delineation and preservation of potential public-land reservoir and waterpower sites, (3) orderly development, conservation, and proper utilization of mineral resources on Federal lands under lease, (4) supervision of mineral operations in order to realize a fair market value from the sale of leases, and in royalties on mineral production, and (5) cooperation with other agencies on mineral-land needs and problems.

**MAPPING AND EVALUATION OF MINERAL LANDS**

The organic act creating the U.S. Geological Survey gave the Director the responsibility of classifying the mineral value of the public domain. There are about 250 million acres of land for which estimates of the magnitude of leasable mineral occurrences have been only partly made. Such appraisals are needed to reserve valuable minerals in the event of disposal of the surface of these lands by the U.S. Government. Estimates are based on data acquired through field mapping and the study of available published and unpublished reports in addition to spot checks and investigations made in response to the needs of other Government agencies. As an aid to the assessment of certain minerals, guidelines have been prepared setting forth limits of thickness, quality, and depth of a mineral occurrence necessary before land is considered to be mineral land.

**Coal standards**

N. W. Bass, assisted by others, prepared new coal standards to replace standards adopted in 1959 but considered to be in need of revision. The new standards limit coal land to that underlain by coal 14 inches or more thick, with a heat value of 4,000 or more British thermal units per pound on an as-received basis for either unwashed or washed unweathered samples. Maximum depth for coal to be considered a valuable resource is set at 6,000 feet. The new standards were approved by the Director of the Geological Survey during fiscal year 1969.

**Classified land**

As a result of Geological Survey investigations, large areas of Federal land have been formally classified “mineral land”. Mineral land classification complements the leasing provisions of the several mineral leasing laws by reserving to the Government, in disposals of public land, the title to such energy resources as coal, oil, gas, oil shale, asphalt and bituminous sands and such fertilizer and industrial minerals as phosphate, potash, sodium, and sulfur. These reserved minerals on public lands are subject to development by private industry under the provisions of the Mineral Leasing Act of 1920. All minerals in acquired lands and on the Outer Continental Shelf are subject to development under comparable acts.

New geologic maps and studies developed to assist in mineral land classification are published in the regular Survey publication series.

**Kaiparowits Plateau, Utah**

Five years ago little was known of the coal deposits in the Kaiparowits Plateau of southern Utah, and estimates of coal resources were about 3 billion tons. An intensive mapping program by Geological Survey geologists has revealed new deposits, and resource estimates are now placed at about 40 billion tons. During fiscal year 1969, H. D. Zeller, working in the Death Ridge quadrangle, discovered an area of about 240 acres with coal beds estimated to contain about 20 million tons of coal under less than 150 feet of overburden.

**San Juan basin, Colorado-New Mexico**

In a study now being completed, J. E. Fassett and Jim Hinds, by a combination of fieldwork and oil-well-cutting studies, have estimated that resources of more than 200 billion tons of coal are present in the Fruitland Formation of the San Juan basin in northwest New Mexico and southwest Colorado.

**Producing oil and gas structures**

During fiscal year 1969, 117 new producing oil and gas structures were formally defined, involving 85,736 acres of land. The largest new defined structure was the Chaveroo-Tabac structure in New Mexico—13,165 acres. An even larger defined structure—the Allison-Bigley structure, New Mexico—with an area of more than 97,000 acres resulted from the revision and consolidation of several previously known defined geological structures.

**WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES**

The objective of the waterpower classification program is to identify, evaluate, and segregate from disposal or adverse use all reservoir sites on public lands which have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. U.S. Geological Survey engineers study maps, photographs, and waterflow records to discover potential dam sites and reservoir basins. S-
lected sites are mapped and engineering and geologic studies are made to determine whether lands qualify for formal classification as valuable sites. Such resource studies provide land-administering agencies with information basic to land-disposal and multiple-use-management decisions. Previous classifications are reviewed as new data become available; if no longer considered suitable for reservoir development, land is released for return to the unencumbered public domain for other possible disposition.

The Geological Survey conducts a limited specialized mapping program, largely confined, at this time, to sites in Alaska. This is necessary to aid in water-resources classification of areas not covered by maps of standard accuracy in the topographic-quadrangle series. River basins are mapped at a scale of 1:24,000, and lake bottoms are contoured by precise sounding surveys.

A review of reservoir and waterpower sites on the Nestucca River in the Coast Range in Oregon was begun in fiscal year 1969. J. L. Colbert and L. H. Godwin, project engineer and geologist, respectively, are preparing topographic and geologic studies of lower and upper reservoirs suitable for a large pump-storage development. Another prime purpose of the lower reservoir will be the regulation of the Nestucca to provide water for diversion to the Willamette River basin for municipal use. The site has a several million kilowatt potential capacity.

SUPERVISION OF MINERAL LEASING

Supervision of competitive and noncompetitive leasing activities to develop and recover leasable minerals in deposits on Federal and Indian lands is a function of the U.S. Geological Survey, under delegation from the Secretary of the Interior. This supervision includes (1) geologic and engineering examination of applied-for lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties (see table 2).

For the past five years, oil and gas production on the Outer Continental Shelf has increased at an average annual rate of more than six times the onshore rate.

In order to keep the ever-growing volume of royalty data up to date, the Geological Survey has put optical readers into use and is utilizing the new Survey I.B.M. 360 digital computer. The time lag between assembly of data and final auditing and reporting has thus been greatly reduced.

LOUISIANA DRAINAGE AND DEVELOPMENT SALES

Three lease sales on Federal land were held during fiscal 1969—two for oil and gas and one for sulfur. These sales followed months of work by U.S. Geological Survey geologists and engineers to estimate the fair market value of the lease tracts. As a result of this study, in cooperation with other interested government agencies, many bids were rejected as being too low. Where bids have been rejected as too low in a sale, the tracts have been sold later at prices as much as 13 times higher, on the average, than the previous bids. One lease for a tract later sold at 30 times the previously rejected bid.

OIL LEAKS AT SANTA BARBARA, CALIF.

During fiscal year 1969, serious oil leaks from a well on a Federal Outer Continental Shelf lease off Santa Barbara, Calif., released a large volume of oil which covered nearby beaches and reportedly threatened sea life. The U.S. Geological Survey assembled a team of geologists and engineers to study all aspects of the leakage and to formulate methods, make recommended

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<th>Lands</th>
<th>Oil (barrels)</th>
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<th>Gas liquids (gallons)</th>
<th>Other 1 (tons)</th>
<th>Value (dollars)</th>
<th>Royalty (dollars)</th>
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1 Estimated in part.
2 All minerals except petroleum products; includes coal, potassium, sodium, and so forth.
tions, and revise operating regulations to prevent or control such occurrences in the future. As a consequence, future Outer Continental Shelf lands will not be offered for sale until there has been a thorough geologic and engineering evaluation of the area in question.

**COOPERATION WITH OTHER AGENCIES**

The U.S. Geological Survey acts as a consultant to other Government agencies in land disposal cases. At their requests, determinations are made on the mineral character of specific tracts of Federal lands under their supervision which are proposed for exchange or sale. Nearly 5,000 such reports are made each year. During fiscal year 1969, the Survey began the mineral evaluation of about 300 tracts of Choctaw-Chickasaw Indian tribal lands in Oklahoma.

**Sulfur prospecting permits**

In the past few years, efforts by a private company to develop a method of extracting sulfur from gypsum and the discovery of sulfur on private and State land in Texas have led to a large number of prospecting permit applications being filed for sulfur on Federal lands in New Mexico—many of the applications are considered to be merely speculative. The filing fee of ten dollars was not considered large enough to cover costs to the U.S. Bureau of Land Management and the U.S. Geological Survey for processing the permits. At the suggestion of these two agencies, the Department of the Interior has levied a charge of 25 cents per acre per year plus the filing fee for each permit application, thus resulting in a considerable reduction of speculative filings.

**Nuclear devices on Federal leaseholds**

An agreement was reached during fiscal year 1969 between the Department of Interior; Austral Oil Co., the gas unit operator; and the U.S. Atomic Energy Commission to detonate a 40-kiloton underground nuclear device in the No. 2 Hayward well of the Rulison oil and gas development unit, near Rifle, Colo. The device is intended to fracture low-permeable gas formations and revive production.
Project GASBUGGY

Project GASBUGGY was an experiment performed by the Atomic Energy Commission, the El Paso Natural Gas Co., and the U.S. Bureau of Mines, to determine the effectiveness of an underground nuclear explosion in increasing the recovery of natural gas by large-scale fracturing of a gas-bearing formation. The nuclear explosive of 26 kilotons design yield was detonated December 10, 1967, at a site in Rio Arriba County, N. Mex., about 55 air miles east of Farmington, N. Mex.

The U.S. Geological Survey recorded seismic waves generated by GASBUGGY primarily to determine travel-time and amplitude variations with azimuth and distance. To accomplish this, 24 seismic recording units were placed along five lines radiating from the shotpoint. Recording distances ranged from approximately 85 to 500 km.

The narrow range of apparent velocities of phases refracted along the upper mantle suggests to D. H. Warren and W. H. Jackson that the crust-mantle interface is structurally uncomplicated in this region. Analysis of the amplitude data for first arrivals shows a disturbed region at distances 300 to 400 km from the shotpoint. Travel times for first arrivals are relatively early for distances approaching 500 km. These facts are consistent with previous observations of an upper mantle layer with a velocity of about 8.0 km/sec underlain by a layer with velocity about 8.4 km/sec.

Crustal structure in central Arizona

D. H. Warren (r0727) has completed interpretation of data obtained in a seismic refraction study of the crust and upper mantle near the Tonto Forest Seismological Observatory (TFO) 10 miles south of the Mogollon Rim near Payson in central Arizona. Arrivals refracted in the upper crust can be attributed to two layers for all the shotpoints south of the rim. The velocity in the upper layer is about 5.9 km/sec with thickness ranging from 2 to 8 km; beneath the upper layer the velocity is about 6.1 km/sec. Northeast of the rim the upper layer seems to be absent; two shotpoints generated crustal arrivals that show only a velocity of 6.2 km/sec. Velocity in the upper mantle is 7.85 km/sec. Crustal thickness is about 21 km near Gila Bend, increasing to about 34 km under TFO, and flattening cut at about 40 km under the Mogollon Mesa and northeast to Sunrise Springs. The relation of topographic elevation to crustal thickness suggests an approach to isostatic equilibrium, which is deduced also from a near-zero regional free-air gravity anomaly. However, in order to make the crustal refraction model fit the observed gravity anomaly values it is necessary to introduce lateral density changes in the upper mantle of about 0.1 gm/cm³.

Gravity and magnetic studies in southern Colorado

Gravity and magnetic model studies were made by M. D. Kleinkopf and D. L. Peterson along two profiles that cross the Trinidad 2-degree quadrangle in southern Colorado. The studies show that the major anomalies correlate with the major geologic features. The most striking gravity anomaly in the quadrangle is a 30-mgal minimum along the eastern edge of the San Luis valley. This minimum probably represents a graben filled with 20,000 to 30,000 feet of Tertiary sediments. Regional northeasterly trends in the gravity and magnetic data may represent fault trends or strongly foliated zones in the crystalline basement. A large positive magnetic bullseye of about 700 gammas amplitude and correlative gravity maximum in the northeast part of the quadrangle may represent a buried intrabasement mass of intermediate to basic composition. This proposed intrabasement body may be related to the Apishapa arch.

Second phase of the LASA calibration

In September 1968, fifteen high-explosive calibration shots were fired on two circles of radii about 75 and 125 km surrounding the Large Aperture Seismic Array (LASA) in eastern Montana. The seismic experiment was the second in a two-phase calibration of the LASA on behalf of the Advanced Research Projects Agency. Preliminary interpretation of the data by J. H. Healy, J. F. Gibbs, and D. H. Warren shows that small anomalies are associated with the upper part of the earth's crust. There are substantial variations in the structure of the middle and lower parts of the crust. Depth to the base of the crust increases by about...
10 km from south to north across the 200-km LASA array.

**Crustal structure in the Western United States**

Claus Prodehl, visiting scientist from the University of Munich, Germany, reinterpreted 46 seismic refraction profiles recorded by the U.S. Geological Survey in the Western United States during the years 1961 to 1964. Curvature on the compressional phase (PmP) reflected from the base of the crust is explained by a relatively large velocity gradient at the base of the crust. This phase is the dominant secondary phase on all the profiles. Using a method of interpretation that allows both continuous velocity-depth functions and the possibility of low-velocity zones within the crust, crustal velocity-profile sections were compiled for the Basin and Range province, the Sierra Nevada, the central Rocky Mountains, and the Colorado Plateaus. The average crustal thickness under the Basin and Range province is 30 km, and the average P-wave velocity is 6.1 to 6.2 km/sec to a depth of 15 or 20 km. There is good evidence for an intermediate layer in the northern part of the Great Basin, but not in its southern part. The crust thickens under the Sierra Nevada to about 42 km between Mono Lake and Shasta Lake and to about 33 km northwest of China Lake. Profiles crossing the central Rocky Mountains north of Salt Lake City and in the central part of the Colorado Plateaus indicate that the crust is more than 40 km thick under both areas.

**Velocity structure in the upper mantle**

In July 1966, twelve United States and Canadian government and academic research institutions participated in a program to record seismic waves generated by a series of 38 five-ton chemical explosions fired in Lake Superior. The participating organizations recorded along profiles radiating outward from the shotpoint nearly to the continental margins. H. M. Iyer, L. C. Pakiser, D. J. Stuart, and D. H. Warren have completed analysis of the seismic traveltime and amplitude data principally from three long profiles radiating northwest, west, and southwest from Lake Superior. They found clear evidence for compressional-wave velocity-transition zones in the upper mantle at depths of 400 km and about 650 km. It seems almost certain that the 400-km velocity transition zone results from the transformation of magnesium-rich olivine to spinel with increasing pressure, and likely that the 650-km velocity transition zone results from transformation of spinel to compact oxide structures.

The most probable composition of upper-mantle olivine is judged to be near Fo85Fa15. The temperature at the center of the olivine-spinel transition zone (400 km) for this composition is in the range 1,200° to 1,500°C, and probably averages about 1,350°C throughout the North American continent. The temperature difference from top to bottom through the transition zone is probably less than 100°C.

**GEOTHERMAL STUDIES**

**A simple relation between heat flow and crustal heat production**

A remarkable linear relation between heat flow, q, and surface heat production, $A_0$, in exposed plutons was found separately by Francis Birch (r2571), R. F. Roy (r2570), E. R. Decker, and D. D. Blackwell, of the Harvard group, at many sites in the United States and by the U.S. Geological Survey (A. H. Lachenbruch, r0795) in the Sierra Nevada:

$$q = q^* + DA_0.$$  (1)

$q^*$ and $D$ are constants characteristic of large geographic areas (heat-flow provinces defined by R. F. Roy and others, r2570). For the Sierra, both laboratories find $q^* = 0.4$ heat-flow units (hfu) and $D = 10$ km. One consequence of this observation is that the empirical relation (equation 1) could not have survived differential erosion (for which there is much evidence) unless the heat sources $A(z)$ were distributed vertically in the plutons (in a gross sense) according to

$$A(z) = A_0 e^{-hD}.$$  (2)

Unlike most geophysical estimates of the distribution of properties with depth, this result is mathematically unique; that is, no vertical source distribution other than equation 2 will do the job. Evidently in the Sierra batholith 0.4 hfu is contributed by the mantle (and possibly lower crust), and $U$, $Th$, and $K$ are distributed vertically in such a way that crustal heat production decreases from the surface value ($A_0$) by $e^{-1}$ with each 10 km of depth. To the extent that this is valid, it is now possible to compute crustal temperatures from quantities measured at the earth's surface ($q$, $A_0$, and their lateral variation). The theory forms the basis for a geothermal model of the Sierra Nevada.

**Heat production in comagmatic rocks**

Evaluation of available data on abundances of heat-producing elements ($U$, $Th$, and $K$) in comagmatic rocks by R. I. Tilling and David Gottfried suggests the possibility of defining and, perhaps ultimately, map-
ping “radiogenic heat production provinces.” Differences in heat production rates for a given magma series can be grossly, but systematically, correlated with differences in chemistry and tectonic association. Variation in abundances of U and Th, which contributed most of the radiogenic heat, cannot be simply correlated with potassium content alone, as is supposed by many geochemists and geophysicists. Rather, the variation in heat production is better correlated with some index which includes the content of CaO as well as of K₂O (for example, the “lime-alkali” or Peacock index 46). In general, the more alkalic the magma series (lower the lime-alkali index), the greater the heat-producing capacity of its fractionated members for a given silica or potassium content. With the recent breakthrough that terrestrial heat flow can be linearly related to heat production of near-surface crustal rocks, these “radiogenic heat production trends” have great bearing on geothermal models and on interpretation of differences in observed heat flow over continents.

A geothermal contrast in the Arctic Ocean

B. V. Marshall and A. H. Lachenbruch found a small systematic difference between heat flow through the Canada Basin and the surrounding regions of rough topography. It implies a marked difference in the earth’s mantle between the two areas. Evidently more heat is escaping from the mantle beneath the basin than from the earth’s surface in the surrounding cordilleran region.

Thermal conductivity of vesicular basalt

E. C. Robertson studied in detail the thermal conductivity of vesicular basalt saturated with air and with water for a porosity range from 0.02 to 0.98. An empirical nonlinear equation was developed which fits these data and previous data for porous sandstone better than the equations previously proposed. The equation relates the composite values of the pure substances in a two-phase aggregate in terms of their volume fractions. The equation is easily modified to account for olivine content in basalt and quartz content in sandstone; it fits the elastic moduli data of glass and sintered perlite. This new relation allows closer prediction of thermal and elastic constants of aggregates and will be useful in studies of the cooling of lava flows, heat conduction, and the response of rocks to seismic waves and elastic deformation.

**ROCK MAGNETISM**

Magnetism of iron-titanium oxide minerals in cooling lavas

Thermomagnetic studies of samples recovered from drill holes through the crusts of cooling ponded lava flows in Alae and Makaopuhi craters, Hawaii were reported by C. S. Grommé, T. L. Wright, and D. L. Peck. These measurements have made it possible to trace the development and alteration of the iron-titanium oxide minerals as the lavas cooled. In most parts of these lavas the magnetic oxide minerals formed at temperatures greater than their Curie temperatures, and hence their natural remanent magnetization is of ordinary thermoremanent origin. However, in some parts of the lavas the magnetic minerals formed below their final Curie temperatures, and thus their natural magnetization is of more complex origin. Measurements of lavas whose magnetic minerals formed below their final Curie temperatures are likely to lead to erroneous results if used to determine the ancient intensity of the earth’s magnetic field.

Magnetism of submarine basalts

Andrew Griscom found that the intensity of the remanent magnetism of Holocene basalt lava pillows erupted on the ocean floor near Hawaii is extremely high, ranging from 1–5 × 10⁻² emu/cm². These values are about 10 times those of subaerially erupted basalts on Hawaii and suggest that the linear magnetic anomaly patterns associated with oceanic ridges may be caused by layers of submarine basalts no thicker than 1 km.

Geomagnetic secular variation in the central Pacific

A paleomagnetic investigation of 54 superposed lava flows in the northwest wall of Mokauweoweo crater, Mauna Loa, Hawaii showed that the geomagnetic field direction changed remarkably little during the period of eruption of the lavas. A reasonable estimate for the total time required for eruption of the sequence of lavas is a few thousand years, and this occurred some time since 10,000 years ago. Because this period of time is short, and considering detailed aspects of the variation of magnetization directions in the lavas, it is tentatively concluded that all the observed variation is due to secular variation of the nondipole part of the earth’s field and that changes in the dipole were negligibly small. This secular variation due to the nondipole field amounts to an angular standard deviation of only 3° in virtual pole positions. R. R. Doell combined this result with other Hawaiian paleomagnetic studies representing longer time intervals to obtain an esti-
mated angular standard deviation of 12° for “wobble” of the main dipole during the last 700,000 years.

**MECHANICAL PROPERTIES OF ROCKS**

Stick-slip, the brittle failure of rock after buildup of stress in a cyclic process of stress rise and drop, was studied further by J. D. Byerlee and W. F. Brace (r1688). They found that under confining pressures of 1 to 7 kb certain rocks failed in a continuous or ductile manner without stick-slip instabilities occurring; these rocks contained a large amount of alteration minerals or had a high porosity. However, the continuous deformation mode in these rocks changed to brittle failure by stick-slip for confining pressures greater than 7 kb. This result has the implication that deep-focus earthquakes could result from stick-slip of almost any rock under high confining load, if the temperatures are not too high.

The propagation of stress waves from preexisting cracks in glass plates carefully loaded along two edges was studied by Byerlee and Louis Peselnick for information on source mechanisms of such elastic waves. The elastic shocks producing the waves originate by sudden propagation of a crack or by frictional sliding on a crack, both for increasing and decreasing loading. These results suggest that: (1) earthquakes may occur when tectonic stress is decreasing, (2) they may occur in otherwise relatively stable regions, and (3) the last motion on a fault opposite to the long-term motion may be due to sliding with a decrease in tectonic stress.

Hydrostatic pressure on polycrystalline rock may cause stress concentrations and produce a phase change at grain boundaries according to Peselnick and Robert Meister, they determined this by making highly precise measurements of wave velocity in limestone under confining pressure. In these experiments they were able to detect a change in the new phase concentration of 1 part in $10^4$ by measuring longitudinal and shear wave velocities at 15 kb pressure at room temperature.

**COMPUTER MODELING OF GEOLOGIC PROCESSES**

**Mechanics of multilayer folding**

J. H. Dieterich investigated the deformations associated with multilayer folding. The study is based on computer simulation of the finite deformations arising from the longitudinal compression of multilayers of rock of various initial configuration and viscous properties. The stress and strain fields in these multilayered models are similar to those for the folding of a single viscous layer in a less viscous matrix. Different models, however, show significant variation of the fold geometry and stress-and-strain fields. The results indicate that “incompetent” layers in multilayered folds exert a strong influence on folding.

**Thermal evolution of the Earth, the Moon, Mars, and Venus**

Effects of selective fusion on the thermal history of the Earth, the Moon, Mars, and Venus was studied by W. H. K. Lee. (r1443, r1444) Thermal evolution of these planetary bodies is simulated on a large-scale computer, and a comparative study has been made by numerical solutions of the heat equation including and excluding selective fusion of silicates. Selective fusion is approximated by melting in a multicomponent system and redistribution of radioactive elements. Selective fusion on the thermal models both lowers (by several hundred degrees centigrade) and stabilizes the internal temperature distribution, and increases the surface heat flow.

The study shows that Earth models with selective fusion give results more compatible with observations of both present temperature and surface heat flow. The results therefore suggest continuous differentiation of the Earth's mantle throughout geologic time, and support the hypothesis that the Earth's atmosphere, oceans, and crust have been accumulating throughout the Earth's history by degassing and selective fusion of the mantle.

Similar studies of the Moon, Mars and Venus indicate that the Moon and Mars are less differentiated, whereas Venus is more differentiated with respect to the Earth. The lack of thermal observations of these bodies, however, does not permit the construction of more realistic thermal models.

**GEOCHEMISTRY, MINERALOGY, AND PETROLOGY**

**EXPERIMENTAL GEOCHEMISTRY**

Theory of binary $P-T-X$ diagrams in the melting range

E. H. Roseboom, Jr., found that 15 types of $P-T-X$ diagram are possible to describe melting relationships involving two intermediate solid phases in binary systems. The minimum information needed to identify the correct type of $P-T-X$ diagram is the compositional relationships of the phases stable at each of the two invariant points where the subsolidus breakdown reaction for each intermediate phase reaches the liquidus.

In collaboration with P. M. Bell (Geophysical Laboratory, Washington, D.C.) experimental melting relationships of jadeite and albite in the
system NaAlSiO₄ = SiO₂ at pressures to 45 kb were confirmed by the above methods. The type of diagram identified for this system was originally thought to be somewhat unusual, but inspection of some other binary and ternary systems projected from H₂O suggests that it is a common type.⁴⁷

Electrochemical measurements of oxygen fugacities applied to igneous petrology

Motoaki Sato made numerous exploratory measurements of oxygen fugacities of igneous rocks related to geological environment and crystallization history using the electrochemical method described previously (see U.S. Geol. Survey Prof. Paper 575–A, p. A158; 600–A, p. A92). His results indicate that: (1) rocks and minerals of deeper origin tend to have lower oxygen fugacities than those of shallower origin at a given temperature; (2) in general, plots of log fO₂ versus 1/7°C for crystallizing basaltic melts are not straight lines but have distinct changes of slope related to the appearance and compositional changes of the crystallizing minerals; (3) more differentiated basaltic rocks with respect to a given sequence of crystallization fractionation, tend to have higher oxygen fugacities than less differentiated rocks at a given temperature; (4) internal equilibrium with respect to intrinsic oxygen potentials of product phases is rarely attained in volcanic rocks; and (5) iron-titanium oxides in volcanic rocks, if adequately quenched, give a good indication of magmatic oxygen fugacities for temperatures below their initial crystallization range, but because of the slope-changes characteristic mentioned above it is not valid to extrapolate such data to higher temperatures with the idea of obtaining the previous magmatic oxygen fugacities.

The liquid-glass transition in silicate systems based on solubility and diffusion of H₂O

H. R. Shaw extended the idea of reaction between H₂O and silicate glasses and liquids to predict the distribution of molecular H₂O and hydroxyl and silicate oxygens in a homogeneous glass or liquid phase. For the system obsidian-H₂O, the ratio of molecular H₂O to hydroxyl in the liquid phase is estimated to range between 0 and 0.05 for concentrations of total dissolved H₂O between 0 and 6 percent by weight.⁴⁸

The temperature dependence of equilibrium constants for the homogeneous reaction is nearly zero above a characteristic temperature of about 700°C, which may represent the glass-liquid transition temperature in nearly anhydrous obsidian. A similar break is noted in published data for H₂O solubility in silica glass at about 1,050°C. Both transitions are also reflected in data for diffusion of H₂O. Other second- or higher-order transitions seem likely in the anhydrous glassy states at lower temperatures. The data also suggest the possibility of concentration-dependent structural transitions in both hydrous glasses and liquids.

Therefore inferences concerning effects of temperatures on H₂O concentrations in magmatic systems should be considered suspect until the appropriate chemical equilibrium functions have been worked out more completely. Chemical activities of H₂O and other components combined with chemical diffusivities of these components appear to give highly significant structural information on silicate liquids and glasses.

Alkali exchange reactions in silicate systems

R. O. Fournier performed alkali exchange experiments on alkali feldspars under hydrothermal conditions that may approximate those at which high-temperature hydrothermal alteration of porphyry copper deposits are initiated. At 600°C and H₂O partial pressures less than 200 bars (solution density 0.05; alkali chloride concentrations 0.5 to 0.05 molal) the ratio of activities of K⁺ to Na⁺ in aqueous solution becomes very large compared to the activity ratios for the same alkali chloride concentrations in experiments at H₂O partial pressures of about 2,000 bars. This means that feldspars of much more potassic composition will be formed at low H₂O partial pressures relative to feldspar compositions formed at high H₂O pressures for the same temperature and alkali ratio in the hydrothermal solution. For example, starting with a bulk composition that would normally form two feldspars (Or₁₀ and Or₆₅) at 2,000 bars and 600°C, only the potassium-rich feldspar (Or₆₅) was produced at 600°C and less than 200 bars. This appears to corroborate field evidence that potassium-rich feldspar can represent an early high-temperature alteration product in porphyry copper deposits.

J. S. Huebner and J. J. Papike extended the study of alkali exchange reactions to an amphibole solution series, the richterite series: (K,Na)NaCaMg₅Si₈O₂₂(OH)₂. This system was chosen as a first test of the method for possible applications to more complicated hornblende compositions. Exchange experiments were performed on both initially sodic and initially potassic richterites, both natural and synthetic, at 850°C and 1,000 bars total pressure using slightly hydrous NaCl, KCl and mixed (K, Na)Cl melts. X-ray diffraction measurements confirm the above results, and the possible application of the method to more complicated systems is noted.
studies of the products establish that the cell dimensions of richterites produced by oxide synthesis and by alkali exchange are identical, indicating that chloride does not substitute for hydroxyl. At 850°C and 1,000 bars all possible A-site alkali ratios could be produced by alkali exchange in either natural or synthetic starting materials. Under the same conditions, two-phase mixtures of all bulk compositions could be completely homogenized. These results clearly establish the absence of a two-phase region in the richterite series under the experimental conditions. Natural richterites tend to be either very potassic or very sodic, indicating the possibility of a two-phase region below 850°C. Crystallographic data at room temperature, however, indicate no significant ΔV of mixing, suggesting that the solution series may also be complete at low temperatures. If so, compositions of natural richterites are controlled by special bulk chemical compositions or by reactions involving other alkali-bearing silicates. The above results suggest that ion-exchange techniques will be valuable in studies of more complex amphiboles.

Geochemical studies of organic-rich sediments in a modern lake

Motoaki Sato and W. H. Bradley probed the sediments of Mud Lake, Fla., to determine chemical profiles of acidity, oxidation states, and dissolved gases. Measurements are made in situ with electrochemical probes; dissolved gases are collected in sampling probes for later analysis by mass spectrometer. The work is not complete, but the important discovery was made that sediments at a depth of 3 feet are rich in hydrocarbons, even though the age of the lake is only 3,000 years. This supports the deductions by Bradley, on other geological and biological grounds, that sediments of this type may be precursors of oil shale. This study is expected to give important information on the genetic conditions and rates at which different hydrocarbons can form in organic fuel deposits.

Solubility of gold in sulfide minerals

The extent to which ore minerals can take gold into solid solution is important in interpreting the mineralogy of ores as well as in extractive metallurgy. P. B. Barton has found that chalcopyrite can dissolve more than 1.6 weight percent Au at 850°C and that much of this gold is exsolved on cooling. In the 600°-700°C temperature range, galena dissolves between 0.1 and 0.5 weight percent Au. Bismuth increases the solubility of gold, whereas silver decreases it; this suggests that the mechanism for the incorporation of gold in galena involves Au⁺³ rather than Au⁺¹. In the same range of temperatures, the solubility of gold in pyrite, pyrrhotite, and arsenopyrite is less, perhaps much less, than 0.1 weight percent.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF ROCK-FORMING SILICATES

Cation distributions in clinopyroxenes of intermediate compositions

Crystal-structure refinements for two C2/c pyroxenes of intermediate compositions, an augite and an omphacite, and for a P2 omphacite were completed by J. R. Clark, D. E. Appleman, and J. J. Papike. Augite from Kakanui, New Zealand, was interpreted by Brian Mason to be of upper mantle origin; its composition is Ca₀.₆₁Na₀.₀⁹Mg₀.₉⁰Fe²⁺Fe⁴⁺Al₀.₁⁰(Si₁.₄₈Al₀.₅₂)O₄.

Site-occupancy refinements for the location of the cations show that Mg and Fe are present in both the M1 and M2 sites. Independent study by Mössbauer spectral techniques (S. S. Hafner, Univ. of Chicago, written commun., 1969) reveals that Fe²⁺ occurs in both sites but Fe³⁺ is present only in M1. The C2/c omphacite having the composition Ca₀.₅₆Na₀.₅₅Mg₀.₉₅Fe²⁺Fe³⁺Al₂/₃Si₂O₆ is from eclogite in Hareidland, Surnes, Norway, and site-occupancy refinements show both Mg and Fe present in M1 and M2 sites. In both the omphacite and the augite the Mg/Fe²⁺ ratio in M2 is greater than 1.0, within the associated errors. These results differ from the Mg/Fe²⁺ distributions previously found in enstatite-like structures (for example, hypersthene) and pigeonite, in which there is a high degree of order and the Mg/Fe²⁺ ratios in M2 are low.

The bond distances and angles in the structures of this omphacite and the augite are very like those found in diopside by J. R. Clark, D. E. Appleman, and J. J. Papike (T1160) showing that the multiple cation contents do not cause significant distortions in the clinopyroxene structure.

Refinement of the site occupancies in the crystal structure of a P2 omphacite from Puerto Cabello, Venezuela, with composition Ca₀.₄₇Na₀.₄₆Mg₀.₄₂Fe²⁺Fe³⁺Ti₀.₂₁Si₁.₄₈Al₂/₃O₈ indicates a semi-ordered distribution of Na/Ca in the four M2-type sites and a nearly ordered distribution of Al³⁺ in two of the four M1-type sites, in agreement with the distribution observed for a Californian P2 omphacite by J. P. Clark and J. J. Papike (r1218). "Ideal" P2 omphacite, Ca₀.₄₅Na₀.₅₅Mg₀.₄₂Al₂/₃Si₂O₆, should have Mg and Al³⁺ fully ordered in the M1-type sites, but (Na+Ce) partly ordered in the M2-type sites, in the ratio 2:1 or 1:2 alternating between sites. A completely ordered 1:1

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Na: Ca arrangement is not likely because of the charge-balance requirements in the structure. The P2_1 omphacites from both California and Venezuela have a degree of order approaching the maximum possible.

**Potassium in the clinoamphibole crystal structure**

Refinement of the crystal structure of a potassium-rich richterite from leucite lamproite, West Kimberly, Western Australia having the composition K_{1.0}Na_{1.2}Ca_{1.2}Mg_{4.4}Fe_{5.2}Fe_{2.2}Ti_{0.4}Al_{0.2}Si_{3.3}O_{20.2}(OH,F)_{2.0} reveals a highly anisotropic electron-density distribution around the A-site central point at (1/2, 0, 0). The anisotropy is attributed to the presence of "half-atoms" of potassium located off the A-site central point. According to this model, there are eight oxygens 3.00 A or closer to potassium, the mean K-O distance for eight being 2.888 A. In the micas only six oxygens are 3.00 A or less from potassium. The coordination of potassium in the clinoamphibole structure is therefore tighter than in the mica structure; this feature may be related to the relative stability of clinoamphiboles and micas in the high-pressure environment of the upper mantle.

**Mg-Fe²⁺ distribution in coexisting olivine and chromite**

The chemical equilibrium in Burro Mountain alpine-type peridotite, California, was investigated by G. R. Himmelberg using electron-microprobe analyses to obtain the Mg-Fe²⁺ distribution for 16 mineral pairs of coexisting olivine and chromite. If one assumes ideal solution behavior, the equilibrium distribution coefficient, K, is shown by E. D. Jackson to be defined as follows:

\[
K = \frac{X_{Mg}^{cl} X_{Fe}^{cl+}}{X_{Mg}^{cl+} X_{Fe}^{cl}} = \exp \left( -\Delta G^{\circ}_{\text{MgFe}^{2+}} / RT - \alpha \Delta G^{\circ}_{\text{MgFe}^{2+} + O_{\text{olivine}}} - \beta \Delta G^{\circ}_{\text{FeAl}^{2+} O_{\text{olivine}}} - \delta \Delta G^{\circ}_{\text{FeSiO}_{3} O_{\text{olivine}}} + \Delta G^{\circ}_{\text{FeFe}^{2+} O_{\text{olivine}}} / RT \right),
\]

where \( X_{Mg}^{cl} \) and \( X_{Fe}^{cl+} \) are the molar fractions of the end members MgSi_{0.5}O_{2} and FeSi_{0.5}O_{2} in olivine; \( X_{Mg}^{cl+} \) and \( X_{Fe}^{cl} \) are the molar fractions of divalent cations in chromite; \( \Delta G^{\circ} \) values with appropriate subscripts are the standard Gibbs, free energies of formation of the olivine and spinel end member compounds; and \( \alpha, \beta, \) and \( \delta \) are the fractions of trivalent cations in chromite. Substitution of the appropriate free-energy values into the above equation allows calculation of the temperature of formation of analyzed olivine-chromite pairs, assuming equilibrium and ideal solution behavior.

The data for the Burro Mountain mineral pairs are compatible with assignment of temperatures of formation ranging from 1,098°C to 1,335°C and averaging about 1,200°C; the range is not significant owing to analytical errors. Because of uncertainties associated with the free-energy values, the temperatures cannot be considered as absolute values, but they do indicate that equilibrium was obtained for all the mineral pairs under virtually the same physical conditions.

**NEW MINERAL DATA**

**Gonophyllite and bannisterite**

Two monoclinic minerals formerly classified as gonophyllite were differentiated by M. L. Smith and Clifford Frondel on the basis of single-crystal X-ray diffraction data. True gonophyllite occurs at the Harstig mine, Pajsborg, Sweden; the Benallt mine, Caernarvonshire, Wales; and the Maple-Hovey Mountains area in Aroostook County, Maine; the crystals are monoclinic, \( \alpha=22.20 \pm 0.07 \) A, \( b=16.32 \pm 0.05 \) A, \( c=24.70 \pm 0.08 \) A, \( \beta=94°20' \pm 10' \), and volume=22,536 A³. Bannisterite, a new mineral, occurs at Franklin, Furnace N. J., and at the Benallt mine, Wales; the crystals are also monoclinic, \( \alpha=22.20 \pm 0.07 \) A, \( b=16.32 \pm 0.05 \) A, \( c=24.70 \pm 0.08 \) A, \( \beta=94°20' \pm 10' \), and volume=34,932 A³. Chemical analysis of gonophyllite from the Harstig mine, Sweden, is: SiO₂, 39.67 percent; Al₂O₃, 7.95; Fe₂O₃, 0.90; MnO, 35.15; CaO, 1.11; MgO, 0.20; PbO, 0.20; K₂O, 2.70; Na₂O, 2.18; Li₂O, trace; H₂O, 9.75; total, 99.85 percent. The chemical analysis of bannisterite from Franklin Furnace, N. J., is: SiO₂, 46.20 percent; Al₂O₃, 4.74; MnO, 23.02; FeO, 6.40; ZnO, 4.67; CaO, 1.52; MgO, 1.99; Na₂O, 0.29; K₂O, 1.21; H₂O, 9.74; total, 99.78 percent. Both gonophyllite and bannisterite show a structural resemblance to stilpnomelane, which is triclinic, pseudotrigonal, and also pseudomonoclinic.

**Zelotes**

G. D. Eberlein and C. L. Christ established a relationship between the chemical potential of water and the measured optic axial angle of zeolites. When loosely bound water is transferred reversibly in and out of the structure, the resulting structural changes are reflected in the optical properties. For the orthorhombic calcium zeolite stellerite (CaAl₂Si₇O₁₈H₂O), the uncorrected optic axial angle, \( (2H_a) \), is related to the chemical potential of water in the crystal, \( \mu_w \), by the general equation: \( \mu_w - \mu_a = 2.303 \frac{R}{T} S \log [(2H_a) - (2H_a)_0] \), where \( R \) is the gas constant; \( T \) is the absolute temperature; \( S \) is a constant for the system: crystal plus immersion fluid; and \( \mu_a \) and \( (2H_a)_0 \) are the standard state values at activity of water, \( (a_w) \), equal to unity.

\[ ^{a} \text{Jackson, E. D., in press, Chemical variation in coexisting chromite and olivine in chromitite zones of the Stillwater Complex: Econ. Geology Spec. Paper 1, Lancaster, Pa., Econ. Geology Pub. Co.} \]
Thus, values of the uncorrected optic axial angle, \((2\theta_c)\), of a stellerite crystal immersed in solutions of known activity of water, \((a_w)\), are directly proportional to \(\log a_w\).

X-ray and infrared absorption studies by I. A. Breger, J. C. Chandler, and Peter Zubovic on the two zeolites, heulandite and clinoptilolite, demonstrate that published analytical data for the structural water content of heulandite are incorrect, and that the mineral contains only two molecules of structural water rather than five or six as had been thought. Clinoptilolite has been found to contain three molecules of structural water. Heulandite undergoes a sluggish transition between 255°C and 330°C that is not directly related to the loss of fixed water; the loss of structural water from heulandite begins at 200°C ± 3°C, whereas that from clinoptilolite begins at 185°C to 190°C. The higher ionic potential of calcium in heulandite is thought to be responsible for the stronger retention of water in that mineral, compared to the clinoptilolite which contains mainly sodium and potassium rather than calcium.

**Mineralogy of the Chilean nitrate deposits**

Synthesis by M. E. Mrose of three phases known to occur in the system CaO-I\(_2\)O-H\(_2\)O led to the identification of a new iodate mineral, Ca(I\(_2\)O\(_3\))\(_2\)-H\(_2\)O, in the Chilean nitrate deposits, Oficina Lautaro. The mineral is associated with soda niter, NaN\(_3\), and lattarite, Ca(I\(_2\)O\(_3\))\(_2\), and occurs as very pale yellow to colorless, long prismatic crystals of monoclinic symmetry, \(P2_1/c\), \(a=8.51\) Å, \(b=10.03\) Å, \(c=7.51\) Å, \(\beta=95° 15'\), cell volume=544.1 Å\(^3\), specific gravity=3.40 (measured), 3.41 (calculated). In transmitted light, arthurite is pale yellow to yellow green; elongation is positive, \(a=1.763\), \(b=1.805\), \(\gamma=1.822\) (both pale yellow to pale yellow green), \(Z\wedge c=+10°\) (yellow green).

**Mixed kaolinite-montmorillonite clay**

A rare mixed-layer clay mineral composed of nearly equal proportions of kaolinite and montmorillonite layers was recognized by L. G. Schultz from X-ray diffraction studies of pottery clays obtained by A. O. Shepard from the Yucatan Peninsula, Mexico. Similar clay has been reported previously only in weathered volcanic material from Japan and altered montmorillonitic claystone from Florida, in both of which the mixed-layer clay is a minor component not easily characterized. In the Yucatan material, minor amounts of kaolin and quartz impurities can be largely removed by fractionation, and a chemical composition is obtained that is compatible with the inferred mineral composition. Electron micrographs by P. D. Blackmon show that the grains are mostly platelets less than 0.1μ in diameter, usually rounded but rarely having a hexagonal outline.

**NEW CRYSTAL STRUCTURES OF A SULFIDE, A SILICOBorate, AND A BORATE**

**Low chalcocite**

The long-standing problem of the crystal structure of low chalcocite \((Cu_2S)\) was solved by H. T. Evans, Jr. (r1354). When the symmetry of the crystal was found to be monoclinic instead of orthorhombic (as has long been supposed as a result of twinning) the structure analysis was carried out on three-dimensional data by means of modern statistical methods. The results revealed a completely ordered arrangement of 12 different sulfur atoms and 24 different copper atoms in the unit cell, based on a hexagonal close-packed arrangement of the sulfur atoms. The copper atoms are all in triangular coordination with sulfur, and some of these triangular elements are arranged in layers as in stromeyerite \((CuAgS)\) and covellite \((CuS)\). The remaining triangles are arranged between the layers in a very complicated manner. This structure analysis throws new light on the properties of the complex Cu-Fe-Ag-S ore system.

**Howlite**

The crystal structure of howlite, Ca\(_2\)SiB\(_2\)C\(_5\)(OH)\(_5\), was solved by J. R. Clark and J. A. Konner, in collaboration with J. J. Finney and Isik Kumbasar (Col-
orado School of Mines) (Finney and others, r2379). The howlite structure provides the first example of a mineral containing both boron and silicon that has boron in both triangular and tetrahedral coordination with oxygen. The structure is a three-dimensional framework with rings and spirals of borate and silicate tetrahedra linking through silicate oxygen atoms to borate chains like those in colemanite. There are both single and double chains of calcium polyhedra in the structure.

Veatchite

Solution of the crystal structure of veatchite by J. R. Clark and C. L. Christ (r1499) shows that its true formula is Sr₂[B₅O₈(OH)]₂-B(OH)₃-H₂O, corresponding to the oxide form 4SrO-11B₂O₃·7H₂O, and so resolving an 18-year controversy over the formula. The space group symmetry is D₇₄. The structure contains a new kind of borate polyanion sheet, [B₅O₈(OH)]²⁻, also found in the closely related structure of the dimorph, p-veatchite, independently solved by Gandimov, Rumanova, and Belov.52 The two structures are the first reported borates in which two kinds of borate anions exist together, the polyanion sheets and the B(OH)₃ group. There are also the first reported structures in which Sr is coordinated by 11 oxygen atoms. The mineral p-veatchite, which crystallizes in space group P₂₁, has been found to date only in marine evaporite deposits (England, Germany, U.S.S.R.), associated with anhydrite. Veatchite has been discovered only in non-marine evaporite deposits of California, associated with colemannite. The slight differences in the crystal structures apparently result from the somewhat different conditions of formation.

MINERALOGY OF THE YELLOWSTONE THERMAL AREAS

Sakuro Honda (Akita University, Japan) and L. J. P. Muffler completed a study of the mineral associations in the cores from U.S. Geological Survey drill hole Y-1, Upper Geyser Basin, Yellowstone National Park. The drill hole penetrated 3.7 m of sinter, 61.6 m of siltstone, sandstone, and conglomerate composed primarily of rhyolite detritus, and bottomed at 65.2 m in an upper Pleistocene rhyolite flow. Temperature measurements were at or near the boiling-point curve at depths greater than 34 m and reached 171°C at the bottom. Associated fluids are near-neutral Na-K-Cl-HCO₃ solutions. The main hydrothermal minerals in the drill core are zeolites, celadonite, 12 Å montmorillonite, quartz, cristobalite, opal, and calcite. Of the zeolites, clinoptilolite and mordenite are common at depths greater than 9 m, whereas analcite is the product of more intense alteration and is common only at depths greater than 34 m. Erionite was found only at 6.2 m. Mordenite occurs with either clinoptilolite or analcite, but clinoptilolite and analcite rarely occur together. Analcite is commonly associated with hydrothermal quartz, whereas clinoptilolite (higher in silica content) occurs with cristobalite, thus suggesting control of zeolite species by silica activity. Aegirine (the only known occurrence in a hydrothermal system) was found at 62.2 m with analcite and quartz. Hydrothermal potassium feldspar was identified only in bedrock rhyolite, where it replaces plagioclase and occurs with quartz in vugs. Distribution of hydrothermal minerals is related to solution composition, pH, silica activity, original abundance of unstable glass, and rock porosity.

VOLCANIC ROCKS AND PROCESSES

RECENT VOLCANIC ACTIVITY

Kilauea Volcano, Hawaii

Much of the effort of the Hawaiian Volcano Observatory staff, headed by Howard Powers, was devoted to studies of increased volcanic activity of Kilauea Volcano. The eruption in Halemaumau fire pit at the summit of the volcano began November 5, 1967, and continued intermittently until July 8, 1968. Two small eruptions on the upper east rift zone followed: the first on August 22-26 near Hiaka Crater and the second on October 7-27 near Napau Crater. During 1967 the eruption in Halemaumau added a maximum of 190 feet of liquid lava above the pre-eruption crater floor. Through December, the eruption included 17 episodes of fountaining and flooding interrupted by 17 episodes of drainback.

On January 1, 1968, fountaining resumed for the 18th episode of vigorous eruption on Halemaumau. Strong fountaining and flooding lasted for about 12 hours, accompanied by subsidence of the summit. Suddenly fountaining ceased, and uplift of the summit began, suggesting that a shallow subsurface reservoir was being recharged; this episode of swelling continued for about 36 hours without eruption. Sudden resumption of fountaining and subsidence initiated another comparable cycle. This pattern of subsidence and refill was repeated 6 times between January 1 and 19, and raised the lava lake to 215 feet above the pre-eruption floor. The main lava lake maintained itself by upward growth of the confining levee walls, but during the hours of vigorous output spectacular overflows of...
the levee flooded the shallow-crusted slopes to the encircling cliff walls of Halemaumau.

The pattern of activity changed with the return of fountaining on January 13; there was no accompanying summit subsidence, the fountaining and visible discharge did not overflow the confining levees, and at intervals there were surges of fluid lava against the cliff walls from cracks remote from the central lake. This activity persisted for long periods without actual cessation of fountaining and drainback. Only 6 pauses, ranging in duration from 2 to 12 hours, occurred during almost 6 months of activity from January 13 through July 8. Even though the lake levees were not overflowed, and the area of the active lake actually contracted, constant addition of new lava under the solidified crust outside the margins of the lake totaled 175 feet in thickness.

The entire 8-month eruption added 110 million cu yd of new lava in Halemaumau and raised the level of the floor to less than 160 feet below the crater rim. Swelling of the summit preceded the eruption, but collapse during the eruption was almost negligible.

Three phenomena were observed which are reminiscent of earlier activity: the pistonlike rise of the whole active floor of Halemaumau, fluctuation of tilt that suggested response to a combination of tide and barometric pressure changes, and the building and destruction of very steep sided spatter cones around some of the lava fountains.

After fountaining stopped in Halemaumau in early July there was no conspicuous deformation of the summit or upper rift zones during July and the first 3 weeks of August. Seismic activity increased somewhat under the rift zones, and several clusters of earthquakes occurred beneath the upper rift zone. A swarm of earthquakes started at 02h49m August 22 accompanied by rapid subsidence of the summit area. Before daylight, heavy fuming issued from a line of new cracks crossing Hiiaka pit crater, and lava fountaining commenced about 06h45m in Hiiaka Crater and from a vent about a mile to the east. During the next 4 days, cracks opened and lava issued from short vents east of Hiiaka Crater, first at 3 miles, then at 12 miles and lastly at 13 1/2 miles distant.

The amount of lava erupted was very small. In Hiiaka Crater, lava welled from cracks in the floor and walls and rapidly fed a lake that grew to 100 feet in depth and 300 feet in diameter. The lava drained back rapidly and left a thin plaster on the lower talus slopes and funnel-shaped bottom of the crater. During this time a small flow covered a few acres a mile east of Hiiaka. Along cracks 3 miles eastward, lava built up spatter ramparts but produced no overflows, although discharge of hot gas started a fire in the vegetation. Small flows issued from fountains at the 12-mile and 13 1/2-mile set of cracks.

After August 26, inflation of the summit continued at a fairly steady pace until October 2. A second eruption from the east rift zone started on October 7, preceded by a swarm of earthquakes and harmonic tremor which began at 11h00m—most strongly on the Makapu'u seismometer. At 14h35m the first fume and lava broke from a fissure on the lower east flank of Kane Nui o Hamo. The fissure extended rapidly eastward, across Napan Crater, to a point 3 1/2 miles downrift. All the new fissures are slightly northwest of the line of March 1965 activity and considerably south of the line that opened in August. Altogether about 5 million cu yd of new lava spread over 1.4 mi including the floor of Napan Crater.

Preliminary analysis of summit ground deformation accompanying both flank eruptions shows that maximum horizontal ground displacement of bench marks for the period of July to October is about 90 cm toward the center of subsidence defined by level and tilt data. Two-dimensional vector displacements, relative to a baseline 10 to 14 km from the summit, are radial to the center of deflation. Stations north of the deflation center have displacements that agree favorably with theoretical displacements predicted for a 2-km focal-depth model, but displacements of stations south of the deflation center fit a 3-km focal depth better. This relationship agrees with an analysis of level and tilt data, which shows that initial deflation takes place from a shallow magma chamber somewhat north of the site of ultimate collapse of a slightly deeper chamber. Three-dimensional vector displacements, derived by vector addition of the horizontal displacements to altitude changes at each geodimeter bench mark, also show that northerly stations reflect deflation at a 2-km source, whereas southerly stations reflect a somewhat deeper chamber.

**Mayon Volcano, Philippines**

J. G. Moore (U.S. Geological Survey) and W. G. Melson (Smithsonian Institution) studied eruption processes and volcanic hazards at the 1968 eruption of Mayon Volcano, located 300 km southeast of the city of Manila. (Moore and Melson, 1930) A series of explosive bursts started in the volcano's summit crater on April 21, 1968, and by May 15 more than 100 explosions had occurred, several deaths had resulted, and more than 100 sq km had been covered by airfall ash, bouldery ash flows, and a lava flow.
Explosions from the summit crater (elevation 2,460 m) ejected large quantities of ash and incandescent blocks to a height exceeding 600 m. Backfall of the coarser material fed nuées ardentes which repeatedly swept down ravines on all sides of the cone. The average velocity of one nuee ardent, determined by study of motion pictures, was 31 m per second over a path length of several kilometers. The largest nuées descended to the southwest, owing to breakdown of the southwestern crater rim, and reached as far as 7 km from the summit. An aa flow also descended 3½ km down this flank.

The nuées ardentes deposited flows that contained large breccia-surfaced blocks (averaging 30 cm in size but attaining 25 m in greatest dimensions) whose interiors were still very hot several days later. A seared zone as much as 2 km wide, but averaging a few hundred meters, surrounds the ash flows. No ash was deposited in these zones, but vegetation is charred and splintered.

Hypersthene andesite from both the lava flow and the nueé ardent deposits is chemically similar, and differs only in the higher vesicularity of ash flow blocks (about 40 percent), and in the presence of alined phenocrysts in the denser lava-flow material. The rock contains 55 volume percent phenocrysts, including plagioclase (An_{56-69}), hypersthene, augite, titanmagnetite, and rare olivine.

**Fernandina Volcano, Galapagos Islands**

K. A. Howard (U.S. Geological Survey) and T. E. Simkin (Smithsonian Institution Center for Short Lived Phenomena) reported on the extensive modifications of Fernandina Volcano, Galapagos Islands, during eruptions in June, 1968 (Howard and Simkin, 1970). The caldera floor of this basaltic shield volcano collapsed as much as 300 m in one of the largest events of this type recorded in historic time. The collapse was heralded by great explosions and was accompanied by 2 weeks of frequent earthquakes. The volume of collapse was 1 to 2 cu km, far greater than that of the erupted products yet recognized, which consist of airfall ash and a precollapse flank lava flow.

The caldera floor, 7 sq km in area, dropped along a deep elliptical boundary fault coincident with that along which the last (unrecorded) collapse occurred. Although the floor dropped as much as 300 m, breakup of the floor was minor. A block about one-half sq km in size, including part of the west caldera wall, dropped 50 to 150 m as an independent unit, however. This block contains a small new explosion crater and numerous fumaroles.

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**TEMPERATURE OF VOLCANIC PROCESSES**

**Crystallization temperatures in silicic magma chambers**

P. W. Lipman found that electron-microprobe analysis of coexisting magnetites and ilmenites from compositionally zoned ash-flow sheets of the Paintbrush and Timber Mountain Tuffs, Nevada, show systematic variations in Fe-Ti oxide composition that correlate closely with bulk rock composition and with inferred position in the source magma chamber. Comparison with experimental data of Buddington and Lindsley indicate that the Fe-Ti oxides of rhyolitic upper parts of the differentiated magma chambers crystallized at 700°±50°C, whereas oxides of quartz latitic lower parts of the magma column crystallized at temperatures as high as 900°C. The trend of temperature and oxygen fugacity is parallel and intermediate to trends for Ni-NiO and MnO-M2O3 buffers. The low indicated temperatures for the rhyolites suggest that they were saturated, or nearly saturated, with water at the time of crystallization.

**Lava lake studies**

Drilling was resumed in the Makaopuhi lava lake on Kilauea Volcano by the staff of the Hawaiian Volcano Observatory in 1968 after a lapse of 2 years. Two 3-inch-diameter holes were drilled in the center of the lake to depths of 54 and 59 feet, respectively. The first hole was successfully cased, and temperature profiles showed the crust-melt interface at the time of drilling to be 52 feet.

Segregation veins (horizontal gash-fracture filling?) were first found between 27 and 28 feet. This depth correlates with the depth of partly molten crust at the time when the surface of the lake abruptly decreased its rate of subsidence as determined by periodic relevelling. Apparently this reflects the time when the crust became partly rooted to the sides of the lake, thus providing an opportunity for horizontal tension fractures to open above the crust-melt interface.

An interesting phenomenon observed during drilling of the first hole into melt was the return of drilling water to the surface as a hot geyser choked with black sand (shattered basaltic melt). Although one sample of dense melt was collected in the drilling bit, it appears that the great quantities of drilling water tended to shatter the melt, something not observed in the 1965–66 drilling when less than one-tenth as much water was used.

A third hole was drilled next to the "island" of crust to which the tramway cable is attached. Core was ob-

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tained from a section of the island root and the melt below. The crust-melt interface was displaced downwards to about 58 feet beneath the island. Most of the core is dense, very fine grained basalt, presumably the normal melt of the lake intruded into and quenched by the cooler island root. More vesicular core represents normal melt of the lake intruded into and quenched by the cooler island root. Drilling extended 8 feet into the melt (66 feet total depth) and ended when the molten lava moved into the core barrel before the drill string could be completely lowered. The 5-foot sample of recovered glassy core apparently lost most of its crystals during flow, a phenomenon also observed in earlier samples collected by "flow-in."

**Thermal history of xenoliths in Ascension Island volcanic breccias**

Laboratory studies by E. W. Roedder on the various types of fluid inclusions in granitic blocks erupted with the trachytic volcanic breccias on Ascension Island in the South Atlantic resulted in a number of conclusions of petrologic significance: (1) before eruption the granitic melt from which the quartz and feldspar of the granite blocks crystallized became saturated and separated globules of an immiscible hypersaline fluid of high density (up to 1.4 g/cm³); (2) presumably during eruption this hypersaline fluid boiled, yielding globules of an "immiscible" low-density, aqueous-CO₂ vapor phase; (3) the temperature of the blocks during eruption was less than 985⁰ and probably less than 710⁰C; (4) cooling through the range 600⁰-700⁰C to below 400⁰ must have occurred in less than 24 hours; and (5) subsequent cooling must have been much slower. In addition, these studies cast considerable doubt on the significance of decrepitation temperatures, as many of the aqueous inclusions withstood heating to temperatures of 100⁰ to even 600⁰C above their homogenization temperature without decrepitation, even though they occurred in loose quartz grains as small as 0.1 mm. Although these conclusions apply strictly only to the Ascension Island rocks, they may well be of broader significance, and similar studies in other volcanic terranes may aid in understanding volcanic processes in general.

**Emplacement temperature of Mount Rainier nuee ardente deposit**

An unconsolidated, bomb-bearing deposit extends westward from Mount Rainier, Wash., for 5 miles down the South Puyallup River valley. D. R. Crandell inferred from the lithology and distribution of the unsorted, coarse-textured deposit that it originated either as a hot mudflow or as a hot, dry flow of rock debris (nuée ardente). According to Meyer Rubin, charcoal from the deposit has a radiocarbon age of 2,590 ± 250 years (W-1587). A study of the thermoremanent magnetism of the deposit under the guidance of G. D. Bath suggests emplacement as a nuee ardente. A northward orientation of the direction of remanent magnetism in 10 out of a total of 14 bombs and rock fragments shows that the debris came to rest before it had cooled through the Curie point. Determinations of the Curie temperature of a bomb and a dense rock fragment by R. R. Doell indicate that the rocks acquired their thermoremanent magnetism at a temperature probably above 400⁰C. Crandell has concluded that the mass moved downvalley from the volcano in a hot, virtually dry condition, and that any water that was present would have been in the form of steam.

**Infrared studies**

Aerial infrared monitoring equipment was used to survey the position and size of hot areas near the summit of Mount Rainier, Wash., in September 1964 and again in September 1966. G. W. Greene reported no detectable change during this 2-year period.

Greene also found that the infrared techniques can quickly delineate the first-order effects of geothermal systems such as hot springs and fumaroles. However, regional surface heating was not detected in two major geothermal areas—The Geysers, Calif., and Steamboat Springs, Nev.

**CHEMICAL VARIATIONS OF VOLCANIC ROCKS**

**San Juan volcanic field, Colorado**

Compilation of available chemical analyses by P. W. Lipman suggests that upper Cenozoic basalts of the San Juan region vary systemically in petrology and chemistry with distance from the Rio Grande depression, a major intracontinental tension-rift structure. Basalts of alkaline affinities, commonly showing evidence of crustal contamination, were erupted east and west of the depression concurrently with its formation, whereas little-contaminated tholeiitic basalt filled parts of the depression late in its history. Eruption of the contrasting basalt types was in part concurrent. The lateral change from alkalic to tholeiitic basaltic volcanism may reflect different conditions of magma generation in the mantle that are related to changes in crustal thickness and thermal gradient across the rift. Recent experimental studies suggest that the variations in magma composition may be due to differing depths of magma fractionation, the tholeiitic basalts originating at shallower depths than the alkaline basalts.
Niobium in lavas and dike rocks

David Gottfried and E. Y. Campbell analyzed 35 lavas from Mauna Loa and Kilauea volcanoes in Hawaii that indicate a clear separation of niobium variation trends in lavas from these two volcanoes. Average values for Nb and TiO₂ are: Kilauea, 20 ppm Nb, 2.68 percent TiO₂; Mauna Loa, 8.5 ppm Nb, 2.0 percent TiO₂. The data are consistent with earlier conclusions based on major-element chemistry that the historic lavas of Mauna Loa and Kilauea are derived from different batches of lava.

Gottfried also found that niobium content of alkalic dike rocks from Augusta County, Va., is especially large and compares with that of corresponding rocks from niobium-rich complexes in other parts of the world. The range and average niobium content (in parts per million) of the predominant rock types are: picrite, 107–155, 150; teschenite, 150–226, 170; and nepheline syenite 200–600, 385. These rocks are also characterized by high concentration of thorium and uranium.

Chemical variations in lavas from Mauna Loa and Kilauea Volcanoes

T. L. Wright completed a study of available chemical analyses of lavas from the two active volcanoes in Hawaii. He found that Mauna Loa lavas show no systematic chemical differences either as a function of the time or the place of eruption. The interflow chemical differences that do exist are dominantly explained by variation in olivine content.

Kilauea lavas differ systematically from the lavas of Mauna Loa in having (relative to constant MgO) a lower content of SiO₂ and Al₂O₃ and higher content of CaO, K₂O, TiO₂, and P₂O₅. The content of "FeO" and Na₂O is similar for lavas of the two volcanoes. The magnitude of these differences are accentuated in time, the composition of 20th century lavas of Kilauea summit being farthest removed from the average Mauna Loa composition. The data suggest that the magma supplying Kilauea and Mauna Loa was originally produced by uniform melting of mantle rock of similar bulk composition. The Kilauea and Mauna Loa magma chambers are now independent but may once have been connected. The change in lava composition with time is explained by partial crystallization in the Kilauean chamber.

Mauna Loa has few lavas which would be called differentiates. Among these, only one has a MgO content of less than 6.4 percent—this one, a submarine lava dredged off the south rift, has MgO content of 5.5 percent.

Kilauea by contrast has numerous differentiated lavas, some of which have as little as 3.9 percent MgO and as much as 56 percent SiO₂.

Successive summit eruptions of Mauna Loa, and particularly of Kilauea, have distinct chemical compositions apparently unrelated to each other either by mixing or by removal or addition of a phenocryst assemblage present in the shallow storage chamber. Kilauea magma is apparently supplied from the mantle in batches of discretely different composition which retain their identity during storage prior to eruption.

Origin of the differentiated lavas of Kilauea Volcano

By combining detailed petrochemical studies with evidence from geophysical investigations, T. L. Wright and R. S. Fiske gained additional insight into processes affecting the chemistry of Kilauea lavas. They find that pockets of differentiated magma have been generated within the east rift zone by filter pressing of the residual liquid from crystallizing bodies of magma emplaced in late prehistoric time. The assignment of a specific time to the production of these magmas comes from calculations, based on the chemistry, which show that the low-MgO differentiates could lie on the liquid line of descent for Kilauea magma of prehistoric composition but not on any liquid line of descent for more recent undifferentiated magmas.

Some eruptions, notably the early part of the 1955 eruption on the lower east rift, represent the composition of the filter-pressed liquid as it is generated beneath the rift. The composition of other eruptions, including that of the later lavas of 1955, is explained by mixing of undifferentiated magma from beneath Kilauea summit with the differentiate in the rift.

The identification of the summit magmas involved in mixing and the fact that they appear in rift eruptions before they appear undiluted in Halemamau suggest that the summit magma chamber is vertically zoned. Thus, rift eruptions are fed from the bottom where younger magma is available, and summit eruptions are fed from the relatively older top of the chamber.

The unique composition of each successive summit eruption also suggests that summit eruptions cease when all the magma of one composition has been erupted from the upper part of the chamber. In order for eruption to occur in Halemaumau, new magma from the mantle must be stored some minimum length.

of time in the summit chamber. The hypotheses permit prediction of future lava compositions—that the composition of the next eruption of Halemaumau will be distinct from that of the 1967 eruption and that this composition will be identified in rift eruptions occurring between 1967 and the time of its appearance in Halemaumau.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Wet Mountain carbonatites

X-ray and optical studies by George Phair and N. L. Hickling show that the carbonatites of the central Wet Mountains, Colo., are made up of variable fine-grained mixtures of carbonates and lesser amounts of one or more of the following: acmite, potassium feldspar, quartz, rutile, goethite, and, locally, plagioclase. Nepheline is absent. Phair subdivided these carbonatites into dolomitic, calcitic, and magnesitic types, depending upon the predominant carbonate. Magnesitic carbonatite is scarce in the Wet Mountains and is known from only one locality elsewhere in the world.

In structure, the Wet Mountains carbonatites range from sharp-walled “carbonate vein dikes” to irregular replacement pods. By addition of breccia fragments of altered granite, replacement pods of dolomite-acmite carbonatite grade into sodic alteration zones in the wallrock. Replacement pods of calcite-rich types are mainly localized in areas of mafic rocks, including amphibolite hornblende gneiss, and metagabbro. The fibrous blue amphibole, magnesioriebeckite, which abundantly replaces magnesia-rich rocks and minerals in sodic alteration zones, has not been found in the carbonatites. In its very high ratios of Fe$^{3+}$/Fe$^{2+}$ and of Mg$^{2+}$/Fe$^{2+}$, this magnesioriebeckite appears to be the closest to the ideal end member so far reported from natural occurrences.

Minor-element distribution in biotite

Preliminary investigation by T. G. Lovering of minor-element distribution in biotite samples from igneous rocks suggests that: (1) concentrations of many of the more abundant minor elements approximate log-normal distributions; (2) some less-abundant minor elements are preferentially concentrated in biotites from certain kinds of rock; (3) characteristic patterns of minor-element distributions distinguish biotites from some different major intrusives in the same area; and (4) high concentrations of certain elements, such as tin and copper, in biotite may indicate the presence of genetically related economic deposits of these elements.

Hornblendedes from granitic rocks of the central Sierra Nevada batholith

Twenty hornblende samples from rocks of 14 plutonic units in the central Sierra Nevada and Inyo Mountains, Calif., were studied in detail by F. C. Dodge. The compositions of the hornblends show only limited correlation with the chemistry of the rocks in which they occur. Hornblendedes from granitic rocks of the eastern Sierra Nevada and Inyo Mountains have a wide range of tetrahedral aluminum content, most as low as three-quarters of an atom per formula unit, whereas hornblendedes from younger granitic rocks elsewhere in the Sierra Nevada batholith contain more than one atom of tetrahedral aluminum per formula unit. Because an increase of aluminum in tetrahedral coordination is considered indicative of higher temperatures of crystallization, the observed differences in the hornblende suggest that older plutonic rocks of the batholith may have been metamorphosed regionally or may have been affected by widespread hydrothermal action prior to consolidation of later granitic rocks.

Source materials for the Twilight Gneiss

The Twilight Gneiss of the West Needle Mountains, Colo., probably originated as volcanic or hypabyssal rocks of latitic, rhyodacitic, and tholeiitic compositions. A Rb-Sr study of this formation by Fred Berkner, Z. E. Peterman, and R. A. Hildreth gives an isochron of 1,805 m.y. for interlayered quartzofeldspathic gneiss of trondhjemitic to quartz monzonitic composition, amphibolite of quartz-normative tholeiitic composition, and metarhyodacite. Rubidium contents of 26.5 to 108 ppm, strontium contents of 114 to 251 ppm, and low K/Na ratios support geologic evidence of a volcanic origin. A low initial Sr$^{87}$/Sr$^{86}$ of 0.7015 suggests the parent magma for these rocks was generated in the mantle.

Chemistry of igneous rocks

Concentrations of Nb, Ta, Zr, Hf, Th, U, and Cs were determined in samples of igneous rocks representing the diabase-granophyre suites from Dillsburg, Pa., and Great Lake, Tasmania, by David Gottfried, L. P. Greenland, and E. Y. Campbell.

A comparison of the abundance of some of these elements has been made with those reported on oceanic tholeiites from the Atlantic and Pacific Oceans. Trace elements with large ionic radii (Th, U, Cs) are present in significantly greater concentrations in the two continental tholeiitic series than in the oceanic tholeiites. However, this does not seem to be true for lithophile elements of smaller ionic radii (Zr and Nb). These trace-element distribution patterns, when considered
with other minor element and isotopic studies, indicate that (1) crystal contamination does not entirely account for differences between continental and oceanic tholeiites, and (2) the oceanic tholeiites do not necessarily delimit the geochemical characteristics of the mantle.

**Mineralogy of Stillwater Complex, Montana**

Pentlandite, pyrrhotite, chalcopyrite, niccolite, and platinum group minerals occur in the G and H chromitite zones of the Stillwater Complex, Stillwater and Sweetgrass Counties, Mont. Detailed mineralogic studies of stratigraphic sections of both zones by N. J. Page show that amounts, relative abundance, and grain sizes of sulfide phases are directly related to primary crystallization processes of a fractionating basaltic magma. Four textural types of sulfide grains and aggregates are present: inclusions in chromite and olivine, grains associated with postcumulus phases, fracture fillings, and grains associated with alteration minerals. Inclusions probably represent both immiscible sulfide droplets and crystalline sulfide minerals trapped by crystallizing cumulus olivine and chromite, whereas sulfide grains in postcumulus material represent interactions between sulfide droplets and trapped magma. Temperature, partial pressures of oxygen and sulfur, and growth rates and settling rates of sulfide and silicate phases were important factors in controlling the distribution of sulfide material.

**Distribution coefficients (Mg/Fe) at 5 kb total pressure**

Garnet, staurolite, biotite, and muscovite separated by Anna Hietanen from aluminum-rich schist in several metamorphic zones north of the Idaho batholith were analyzed chemically. The analyses show that the bulk composition of the host rocks is fairly uniform. The presence of andalusite, kyanite, and sillimanite indicates that pressures during metamorphism were about 5 kb; temperatures increased toward the batholith from about 400°C in the garnet zone to 600°C in the sillimanite-muscovite zone. The distribution of Mg and Fe between garnet and biotite changed with temperature, the distribution coefficient $K_D$ (Mg/Fe) (garnet/biotite) increasing from 0.106 in the garnet zone to 0.224 in the sillimanite-muscovite zone. $K_D$ is 0.137 in rock recrystallized at the temperature of the andalusite-kyanite-sillimanite triple point, corresponding to a temperature of 520° to 580°C.

**Zeolitic mineral equilibria**

A. L. Albee (California Institute of Technology) and E-an Zen analyzed the theoretical zeolitic mineral assemblages by using the method of multisystems as an extension of a similar analysis of simpler zeolite assemblages in the perspective of new petrographic information, especially on the pumpellyite and (c+e) prehnite-bearing assemblages. Using the chemical potential of $H_2O$ and $CO_2$ as independent variables under isothermal and isobaric conditions, they determined the petrographic data can be reconciled with the theoretical framework. They concluded that transition from sediments to greenschist facies does not have to pass through the zeolite facies. Furthermore, the zeolite facies is not necessarily subgreenschist facies in its metamorphic grade. However, assemblages bearing actinolite appear to require change of variables other than the potentials of $CO_2$ and $H_2O$, a conclusion wholly consonant with widely accepted geologic and petrologic data.

**Metamorphic studies of the United States**

B. A. Morgan III compiled information on belts of regional metamorphism of Precambrian age in the southern part of the Canadian Shield and in the scattered Precambrian exposures of New Mexico, Colorado, South Dakota, Wyoming, Montana, and parts of Utah. Multiple episodes of metamorphism, glacial coverage, discontinuous exposures in the Rocky Mountains and inadequate study of large areas prevent a satisfactory compilation of isograds or of metamorphic facies on a map, except at a small scale and in very general terms. However, distinctive facies-series patterns of regional metamorphism can be recognized and broadly related to the radiometric age of the metamorphism.

The Lake Superior province in central and northern Minnesota shows greenschist and amphibolite facies of low-pressure high-temperature metamorphism in most places; cordierite and transitions between andalusite and sillimanite are common. The metamorphic rocks in this province have a radiometric age greater than 2,000 m.y. Rocks of the same age extend from central Minnesota westward in the Bighorn, Wind River, Teton, and Beartooth Mountains of Wyoming and Montana. In the extreme west, granulite facies prevail locally.

Exposures in northern Michigan are in an intermediate facies series and exhibit many characteristics of the Barrovian sequence (except that kyanite is erratic in occurrence). Correlative rocks extend from northern Michigan and southern Minnesota across Wisconsin to the Black Hills of South Dakota, the Laramie Range and Medicine Bow Mountains of Wyoming, and the basement of the Uinta Range of Utah.

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The radiometric age of this belt is between 2,000 m.y. and 1,400 m.y. Rocks of broadly similar age and similar metamorphic facies series also crop out in southwestern Montana in the Ruby and Tobacco Root Mountains.

The rocks of the Front Range of Colorado have an age of slightly less than 1,400 m.y., and are also in a low pressure-high temperature facies series, characterized by their abundant amphibolites of cordierite-anthophyllite, andalusite-sillimanite transitions, and no kyanite. The metamorphic relation between this area and the Sangre de Cristo Mountains in northern New Mexico is not clear. This latter area has assemblages of andalusite-kyanite-sillimanite transitions, abundant staurolite-garnet-kyanite assemblages, and generally is typical of an intermediate, or Barrovan, metamorphic facies series.

Serpentinization of Sierra Nevada ultramafic bodies

In the Bucks Lake quadrangle, California, two ultramafic bodies, each 2 to 3 miles wide, are increasingly serpentinized toward their margins, according to Anna Hietanen. In their central parts, the major constituents—olivine, augite and, in places, colorless primary amphibole—are traversed by numerous irregular cracks, 0.01 to 0.03 mm wide and by a few wider (0.3-0.5 mm) fractures subparallel to a crude foliation. These cracks and fractures are filled by chrysotile and lizardite. A set of still wider through-going fractures (2-20 mm wide) that parallel cross joints are filled by antigorite flakes that grew normal to the fracture walls and by central cores of magnesite. The fracture fillings of antigorite widen from the centers of the ultramafic bodies toward the borders. A short distance outward from the core areas, patches of antigorite are present in the olivinite adjacent to the fracture fillings. Farther outward, the ultramafic rock between fractures is serpentinized and consists of remnants of olivine and lesser amounts of chrysotile, lizardite, and magnesite embedded in a matrix of antigorite. Still farther outward, talc is a common mineral, appearing first in the antigorite zone, to 50 wide, tremolite is a major constituent.

The first alteration along the irregular tiny cracks probably was a late magmatic process, whereas all later serpentinization and stannitization resulted from differential migration of H₂O, CO₂, SiO₂, and CaO into the ultramafic bodies, chiefly along the through-going fractures. H₂O and CO₂ traveled farthest into the bodies to cause the serpentinization; SiO₂ traveled shorter distances to form talc; and CaO moved inward only slightly to form tremolite.

Origin of Alpine-type peridotites and related rocks

Several lines of evidence correlated by Thayer indicate that the great chromite-bearing olivine-rich alpine-type peridotite and dunite masses of the world, and spatially associated basaltic lavas, cannot have been formed in a single process involving only partial fusion of mantle material. Reticulated textures in alpine-type peridotites, especially peridotites containing chondrite and plagioclase in segregated masses of chromitite and intimately associated with magnesium-rich gabbro, show that the peridotites and gabbros were formed in the mantle by gravitational settling of crystals from magma, as in the lower parts of many stratiform layered complexes. Partial melting hypotheses generally postulate only 15 to 20 percent of generated liquid, an amount insufficient to permit the formation of cumulus textures. Furthermore, studies of xenoliths in basalt show that mantle peridotites are different in their mineral content from alpine-type peridotites. Clinopyroxene predominates over orthopyroxene or is the only pyroxene in those inclusions peridotites. Clinopyroxene predominates over orthopyroxene by far the dominant pyroxene in alpine peridotites. Podiform chromitite deposits, genetically related alpine peridotites and gabbros, and possibly more salic comagmatic rocks, as well, are probably formed in the upper 25 to 30 km of the mantle by gravitational differentiation processes, and tholeiitic magma is generated by fusion of material at much greater depths.

Conditions of crystallization of small mafic intrusions in Missouri

Electron microprobe analyses were made by G. A. Deeborough of adjoining grains of ilmenite and titaniferous magnetite from eight samples of gabbro distributed over an interval of 200 feet of drill core in the Shepherd Mountain intrusion near Pilot Knob, Mo. The resultant data when related to experimental data of Buddington and Lindsley indicate the following intratelluric conditions: temperature 760°-820°C, and log-oxygen fugacity of -14.5 to -16.0. There values are comparable to those for the Skærgaard intrusion and indicate slow cooling.

Anorthosite belts

Anorthosites plotted by Norman Herz (r2127) on a predrift reconstruction of the earth fall largely into two belts: one passes through Duluth, Minn., Rose-
land, Va., southern Greenland, the Outer Hebrides, Scandinavia, and the U.S.S.R.; the other passes through southern Brazil, Angola, Tanzania, Madagascar, India, Antarctica, and Australia. Most anorthosites yield radiometric ages of 1,300±200 m.y., an age that is not related to any known Precambrian orogenic event. These facts, in conjunction with the likelihood that the anorthosites originated in the lower crust or upper mantle, suggest the possibility that anorthosite genesis and emplacement may be related to a thermal event, possibly one that accompanied moon capture.

**Rock types and model trend of granitic rocks of the Coast Ranges**

Petrographic study of granitic rocks of the California Coast Ranges (excluding the Santa Lucia Range) by D. C. Ross showed the following distribution of rock types: quartz monzonite, 180 sq mi; granodiorite, 165 sq mi; quartz diorite, 105 sq mi; and diorite and gabbro, 5 sq mi. Brief, general published descriptions of the Santa Lucia Range granitic rocks indicate that their addition to the other Coast Ranges granitic rocks would make granodiorite the most abundant granitic rock exposed in the Coast Ranges. Plots of more than 200 modes on a quartz-plagioclase-potassium-feldspar triangular diagram show a grossly constant quartz content through the entire compositional range of quartz monzonite to quartz diorite. This is in marked contrast to many other granitic suites in which quartz decreases in abundance with increasing plagioclase. These new data on compositional range and abundance of rock types need to be taken into account when inferences are made about crustal composition near the western continental margin.

**Temperatures of metamorphism in the Salton Sea geothermal system, California**

Metamorphic mineral assemblages that are forming in the Salton Sea geothermal system and also in surrounding areas of the Salton Basin at temperatures as high as 360°C were carefully studied by L. J. P. Muffler and D. E. White. Montmorillonite is absent as a discrete phase above about 100°C; illite-montmorillonite is converted to potassium-mica at temperatures above 210°C. The formation of ankerite by conversion of calcite or dolomite, or both, takes place at temperatures above 120°C and possibly above temperatures as low as 88°C. The important reaction of dolomite + ankerite + kaolinite to produce chlorite + calcite + CO₂ can occur at temperatures above 180°C and possibly between 180° and 125°C. Epidote can form, perhaps from muscovite, calcite, quartz, and ferric iron, at temperatures at low as 290°C.

**DISTRIBUTION OF ELEMENTS**

**Cambrian sandstones**

A. T. Miesch and J. J. Connor interpreted the depositional environment of basal Cambrian sandstone in the cratonic part of the Western United States from a comparison of sampling interval with compositional variation. Stratigraphic sections 50 miles apart do not differ in composition significantly more than sections 10 miles apart; sections 250 miles apart, on the other hand, differ significantly more than sections less than 50 miles apart. This indicates that most of the compositional variation in the basal Cambrian sandstone is either local or regional in scale; very little variation on intermediate scales is present. This type of variation is more consistent with fluvial, erosional, trans- portational, and depositional processes than with those of littoral marine types. However, the composition of the sandstone as well as its textural and compositional character suggests that it is a marine deposit. Transportation by marine currents would probably give rise to regional variation with extremely little local variation. If the Cambrian sediments had been derived directly from Precambrian crystalline rocks and deposited in a beach environment they would probably exhibit compositional variation on a continuous range of scales, as does the present Precambrian surface. If the Cambrian sandstones represent fluvial deposition, the regional variation may be attributed to variation among source areas and drainage basins, and the local variation to the lack of thorough sediment mixing within individual streams or stream systems. A small amount of variation on intermediate scales may reflect homogeneity among streams and stream systems within individual drainage basins. These considerations suggest that the lithology and petrology of the basal Cambrian sandstone in the cratonic areas of the Western United States and the nature of the compositional variation within it are best explained as a result of reworking of fluvial deposits in a beach environment.

**Soils and plants**

H. T. Shacklette, J. G. Boerngen, J. M. Bowles, and J. C. Hamilton completed a computer-based file of chemical data on soils of the United States. The file contains data for 25 elements in nearly 1,000 soil samples collected at approximately 50-mile intervals along major highways throughout the country. The sampling was conducted over the past 7 years by many different persons traveling to and from other field investigations. Most of the analyses were made by rapid semi-quantitative spectrographic methods. The data file is being used to determine the expected values of element
concentrations in soils of the United States and the corresponding frequency distributions. Maps showing the geographic variations in soil composition are also being prepared. The statistical compilations and maps are being made by automatic procedures provided in program systems with which the soil data file is integrated.

**Soil and plant geochemistry in Kentucky**

R. R. Tidball found in a statewide study in Kentucky that the total concentrations of 21 chemical elements determined by spectrographic methods do not vary significantly among Red-Yellow Podzolic soils in various physiographic and soil-association areas. The physiographic and soil-association areas correspond in large part to the regional geology. However, the soils in the Knobs area of central Kentucky, underlain locally by organic-rich Chattanooga, New Albany, and Ohio Shales of Middle Devonian to Early Mississippian age, contain significantly larger amounts of iron, magnesium, scandium, titanium, and vanadium than the same type of soil in the other areas. Also, the soils in the western coal fields contain significantly larger amounts of manganese and sodium. Hickory trees growing on these soils in the Knobs area contain more lithium, nickel, and titanium than these growing on the same soil type in other areas. Oak trees contain significantly low amounts of aluminum and iron over a wide area of southeastern Kentucky (the Eastern Pennyroyal and eastern coal fields areas). In general, the composition of this soil type varies little with the rock type on which it is developed, and the chemical compositions of hickory and oak trees reflect the geology even less.

Tidball and J. J. Connor investigated the changes in element abundance that occur on weathering of a bedrock parent to a residual zonal Red-Yellow Podzolic soil in a local area of west-central Kentucky, about 30 miles south of Louisville. The parent is the organic-rich New Albany Shale (Devonian), and soils developed on it belong to either the Trappist or the Rarden soil series. Of 17 elements investigated, 12 tend to be distributed through the weathering profile in one of three distinct patterns. Manganese, zircon, titanium, and strontium increase systematically from parent to the A horizon. Because zirconium is most likely present in resistant zircons, a systematic increase upward suggests simple residual accumulation of zircon during soil formation. Such a process might also account for the distribution of titanium which, like zirconium, tends to occur in resistant minerals. The increase in manganese and strontium may also reflect residual accumulation but in what minerals is unknown. Boron, copper, nickel, and vanadium decrease systematically from parent to the A horizon. Such a pattern may be ascribed to some kind of continual leaching during soil formation. Chromium, iron, gallium, and scandium tend to occur in nearly equal amounts in the parent and the A horizon, but are enriched in the intermediate zones, probably reflecting element mobilization in the A horizon by chelation with organic acids followed by element adsorption on clays in the clay-rich B and C horizons. Analysis of variance indicates that five elements, barium, molybdenum, lead, cobalt, and yttrium, exhibit no significant differences among various parts of the profile.

**Element concentration by *Atriplex***

Other studies of plant geochemistry by H. L. Cannon showed that the concentration of Ca + Fe + Na in all species of *Atriplex* is about 40 percent of the ash. Substitution of sodium for potassium appears to be a species characteristic. *A. canescens* contains less than 1 percent Na and 27 percent K. A group of species, including *A. confertifolia*, takes up a little more Na than K. A third group, including *A. hymenoptera*, contains about 30 percent Na and only 5 to 6 percent K. The distribution of species may be useful as a guide to the salt content of ground water and hydrologic conditions in alluvial basins.

**Sampling techniques**

Computer simulation methods were used by R. R. Tidball to study the effects of sampling error on the detection of geochemical anomalies and the accuracy of geochemical maps. Preliminary results indicate that the general configuration of the geochemical pattern can be determined with a high degree of confidence if a number of random samples are taken at each sampling locality sufficient to reduce the variance of the locality mean to a value at least equal to the variance among locality means. If the number of samples taken at each locality is further increased sufficiently to insure that the expected variance between any two localities is significantly larger (at the 0.05-confidence level) than the variance within localities, the geochemical highs and lows become apparent. With increased sampling intensity, false extremes (anomalies) are very infrequent.

**Gold content of marine sediments**

Of the 24 samples of marble collected by D. A. Seeland from the Grenville Series of northern New York, 9 were found to contain more than 20 ppb Au. The
mean gold content of the 9 samples was 60 ppb. Samples of three other limestones, one sample of halite, and one sample of gypsum contained 20 to 60 ppb Au. These analytical results suggest that syngenetic chemical processes may result in the removal and concentration of the gold in sea water.

**Silver content of Phosphoria Formation, Jackson Hole, Wyo.**

The silver content of phosphatic black shale and mudstone collected by J. D. Love from near the base of the Phosphoria Formation (Permian) was determined on samples from four localities near Jackson, Wyo. The sampled zone lies 7 to 14 feet above the base of the Phosphoria, is 1 to 7 feet thick, and contains 40 to 70 ppm Ag.

**Trace elements in graphitic schist, Alabama and Georgia**

Of 100 samples of graphitic schist of Precambrian and Paleozoic age collected by F. G. Lesure in northeastern Alabama and northern Georgia, 24 contain detectable amounts of gold ranging from 0.02 to 3.8 ppm. The gold-bearing samples came from the Wedowee, Ashland, Canton, and Brevard Formations of Crickmay 59 mostly from the Blue Hill-Gregory Hill mine in Tallapoosa County, Ala. Gold-bearing samples from the eastern outcrop belt of the Wedowee Formation seem to contain a little less B, Ba, Co, Cr, Cu, Fe, Mn, Mg, Ni, Pb, Sc, Ti, V, and Y than barren samples from the same unit, and about the same amount of Be, La, Mo, Nb, Sr, Zn, and Zr. The trace-element content of the graphitic schists is similar to the trace-element content of eugeosynclinal black shales and about the same as that of an average shale.

**ADP system for geochemical data**

An automatic data-processing system for geochemical investigations was put into operation during 1968. The system operates on the Geological Survey's nationwide computer system, but is controlled principally from the Denver offices by R. V. Mendes. Data are entered into the system from the Denver computer terminal and are placed on magnetic tapes written and stored in Washington, D.C. The data include up to 390 kinds of analytical determinations, as well as coded descriptions of the samples analyzed and, to a minor extent, the environments from which they were taken. Other data include the locations from which the samples came and various kinds of administrative information. The file may be searched, and selected data retrieved with almost complete generality. Retrieved data may be listed or may be automatically entered into a system of computer programs for statistical summary and analysis, or onto magnetic tapes used to drive an XY plotter for the preparation of geochemical maps.

**GEOCHEMISTRY OF WATER**

**Effect of sodium bicarbonate on solubility of silica**

The silica content of water from hot springs and wells has become widely utilized as an aid to estimating underground temperatures of aquifers in geothermal areas. The method generally gives the temperature of last equilibration with quartz and assumes that various other chemical species dissolved in the natural waters do not appreciably affect the solubility of quartz. Sodium chloride, the most commonly dissolved salt in water, is known to have no appreciable effect on quartz solubility. On the other hand, Na₂CO₃ is known to increase the solubility of quartz at moderate to high temperatures, probably because of its effect in raising pH. However, Na₂CO₃ is rare in natural waters, whereas NaHCO₃ is common. Therefore, R. O. Fournier carried out an experimental study at 300°C to check on the possible enhancement of quartz solubility in NaHCO₃ solutions. Under conditions that preclude the decomposition of NaHCO₃ to Na₂CO₃ + CO₂ + H₂O (high partial pressure of CO₂ and (or) moderate to low pH), NaHCO₃ in concentrations up to 0.5 molal was found to have no effect on quartz solubility. Thus, in most natural hot-spring systems the dissolved SiO₂ content of the water need not be corrected for NaHCO₃ when applying the "silica geothermometer."

**Gold in hot-spring deposits, Wyoming and Nevada**

J. J. Rowe, using activation analysis methods, determined the gold contents of samples of hot-spring deposits from Yellowstone National Park, Wyo., and Steamboat Springs, Nev., collected by R. O. Fournier and D. E. White. Siliceous sinter from Old Faithful contained 5.5 ppb Au, and sinter from Beryl Spring contained 5,500 ppb. Metal-bearing siliceous muds deposited from thermal waters at Steamboat Springs contained as much as 200 ppm, and gold values there ranged from about 40¢ to $240 per ton of dried mud. Steamboat sinters are more nearly representative of average gold content; the average of 3 analyses is 0.11 ppm, or about 13¢ per ton. The preliminary data from all samples suggest that deposits within or near spring vents are much higher in gold than deposits far from known vents.

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**Computer relates factors governing hot-spring boiling points**

The calculation of temperature at which a solution in a subsurface channel will just begin to boil is a most important factor in the study of hot springs and hydrothermal ore deposits. D. E. White had previously calculated the depth-temperature curves for incipient boiling for pure water and 25 weight-percent NaCl solutions. From all available data for the vapor pressure and density of NaCl solutions, J. L. Haas, Jr., wrote a computer program interrelating depth, pressure, salinity, density, and temperature for all NaCl-H2O mixtures up to 300°C. The results reflect the available data within a precision of approximately 0.5 percent.

**Dolomite formation**

Ivan Barnes reported that carbonate cements in stream conglomerates in the Coast Ranges of California are a continuous spectrum of carbonate minerals from calcite to dolomite. The available C14 dates give ages in the range 3,390–7,560 years B.P. Calcite or aragonite are probably the first phases to form, and the intermediate carbonate minerals are formed from the calcite and aragonite by reaction with coexisting aqueous solutions.

**Travertine in the Grand Canyon of the Colorado River**

Travertine deposits in Arizona nearly 600 feet high and extending for 2.5 miles along the Colorado River at the mouths of the Little Colorado River and Royal Arch Creek and near Tapeats and Deer Creeks are being eroded, according to M. E. Cooley. The travertine deposits may have been precipitated by ground-water discharge from ancient springs before the Colorado River had downcut to its present level. The travertine that is being precipitated today in the Little Colorado River gorge (flow about 220 cfs) and along Havasu Creek (flow 60 cfs) is from ground water that has traveled long distances in the Black Mesa hydrologic basin and Coconino trough, respectively.

**Calcite cement in the clastic sediments of the Tucson basin**

Carbonate cementation of Tertiary and Quaternary nonmarine clastic deposits by ground water in the Tucson basin, Arizona, was investigated by R. L. Laney. Most of the ground water contains less than 1,000 mg/l of dissolved solids—mainly calcium, sodium, bicarbonate, and sulfate. Chemical changes occur with increasing depth—sodium increases and calcium decreases, dissolved-solids content generally decreases, and pH increases from less than 8.0 to more than 9.0. At depths of less than 500 feet, calcite is disseminated throughout the water-bearing material where the water is satura-
the proportion of soil seepage water increases. After peak discharge, when the proportion of soil seepage water is great, silica concentrations reach a maximum and sulfate a minimum. As discharge decreases, silica content initially tends to remain high and then slowly decreases while sulfate content gradually increases as ground water inflow becomes a significant factor in stream discharge. During storm runoff the proportion of chloride, sodium, and potassium in the dissolved salts tends to increase and that of calcium and magnesium tends to decrease. An understanding of these relations is necessary in modeling of the water chemistry of streams and in estimating input to the oceans.

**Sulfur-oxidizing bacteria in sulfurous warm springs**

Sulfur-oxidizing bacteria capable of producing large quantities of sulfuric acid were found by Robert Schoen in soil samples from sulfurous hot springs in France, Italy, and Switzerland. The abundance of these bacteria in soils that are hostile to most other living matter makes them locally important as agents in rock weathering and in the corrosion of sewer pipes. Previously reported from sulfurous hot springs in New Zealand, the western United States, Kamchatka, and Japan, the isolation of sulfur-oxidizing bacteria from European soils further demonstrates their wide distribution.

**Solubilities of cryolite and ralstonite**

C. E. Roberson and J. D. Hem (r1679, r1153) prepared a series of graphs showing the solubility of gibbsite and cryolite in water at 25°C and a pressure of 1 atmosphere as a function of total fluoride and sodium concentrations and pH. The activity product constant for the precipitation of cryolite determined in this work was 10^{-38.84}. The effects of ionic strength and sulfate ion concentrations also were studied experimentally to verify calculated solubilities. Cryolite and ralstonite were identified by X-ray diffraction in precipitates aged in these solutions less than 24 hours. Both minerals were present in solutions whose pH ranged from 3.95 to 6.78. Cryolite was present alone in more alkaline solutions. In the presence of sulfate, an amorphous precipitate formed which gave the X-ray pattern of alunite after 16 months of aging in solution at pH near 5. These results further demonstrate the dependence of aluminum solubility on pH and on activities of other ions and help explain the usual low concentrations of aluminum in natural water.

Sodium-aluminum-silicate gels from the Lake Magadi area of Kenya are reaction products of volcanic rock weathering in an alkaline saline environment, according to B. F. Jones. Silica-to-alumina ratios are similar to those of the amorphous material in average stream sediments, and some of the material has X-ray properties of a very crude layer silicate structure. The differences between these gels and products of dissolution of volcanic rocks elsewhere apparently lies only in the solutes sorbed from more-saline water (H. P. Eugster and B. F. Jones, r2152).

Analysis of interstitial brines from lake-bottom and playa sediments in closed basins of south-central Oregon indicates that a large quantity of solutes is stored in such fluids. High concentrations in interstitial brines can result from capillary evaporation or entrapment of fossil salines, solid or liquid, in very fine-grained, impermeable lacustrine strata. Solution ion ratios and SiO_2 content indicate the relative importance of silicate dissolution, organic decay, sorption, or other diagenetic reactions (B. F. Jones, A. S. Ven Denburgh, A. H. Truesdell, and S. L. Rettig, r2169).

Study of playa sediments associated with highly alkaline brines at Alkali Lake, Oreg., has identified magadiite—NaSi_7O_{13}(OH)_3·3H_2O—which has formed from solution by evaporative concentration or pH changes on dilution. Veins of magadiite are apparently related to syneresis cracking in very fine-grained clays derived from pyroclastic detritus.

An evaluation of ion pairs and coordination complexes in natural brines indicates that quantitative prediction of brine compositions and reactions needs much additional data on mineral stabilities, dissociation constants of complexes, and ion activity coefficients in concentrated solutions (A. H. Truesdell and B. F. Jones, r2365).

**ISOTOPE AND NUCLEAR GEOCHEMISTRY**

**ISOTOPE TRACER STUDIES**

**Geochemistry of potassium, rubidium, strontium, and barium in basalts**

A necessary prerequisite for interpreting strontium isotopic data in magmatic rocks is an understanding of the igneous geochemistry of strontium and rubidium. C. E. Hedge obtained concentration data as part of his strontium isotopic studies, and the behavior of rubidium and strontium in the magmatic environment is now reasonably well understood. The four elements—potassium, rubidium, strontium, and barium—are approximately covariable in basic and ultrabasic rock.

Strontium is commonly assumed to follow calcium, but this is only true in the acidic magmas where plagioclase has played a significant role. The three elements increase with increasing alkalinity in basaltic rock,
and strontium concentration is an almost infallible indicator of the degree of silica saturation in basalts. Nearly all tholeitic basalts have less than 400 ppm Sr, whereas alkali-olivine basalts have more than 400 ppm, and nepheline basalts contain up to 3,000 ppm Sr. Ratios among the four elements are more constant in oceanic basalts than in their continental equivalents. This suggests a more heterogeneous source for the continental basalts. There is little correlation between the Rb/Sr ratio of basalts and their respective Sr²⁷/Sr²⁸ ratios—especially in continental basalts.

**The Granite Mountains—a source of the central Wyoming uranium deposits?**

Uranium, thorium, and lead concentrations and lead isotopic compositions were determined by J. N. Roscholt and Z. E. Peterman (1988) on total rocks and microclines from widely separated parts of the Granite Mountains of central Wyoming, as shown in the table at the bottom of this page. Linear relations between Pb²⁰⁶/Pb²⁰⁴ and Pb²⁰⁷/Pb²⁰⁴ and between Pb²⁰⁶/Pb²⁰⁴ and Th²³²/Pb²⁰⁴ for the total-rock samples define 2,800-m.y. isochrons which agree approximately with Rb-Sr dating. In contrast, U²³⁸/Pb²⁰⁶ ages are anomalously old by a factor of four or more. Isotopic data indicate that the common lead originally incorporated in the microclines was partly mixed with radiogenic lead from other phases during a metamorphic event that occurred about 1,500 m.y. ago, a time of extensive diabase dike emplacement in the granite. The unusually low U²³⁸/Pb²⁰⁴ values coupled with high Pb²⁰⁶/Pb²⁰⁴ ratios indicate that uranium contents considerably greater than those present in the surface rocks would have been required to generate the radiogenic lead. The most feasible interpretation is that uranium was leached from these near-surface rocks at some time during the Cenozoic, thus providing a major source for the uranium deposits in the central Wyoming sedimentary basins.

**A lead isotopic study of galenas from mining districts in Utah**

Galena lead samples from deposits in major mining regions of Utah were examined isotopically by J. S. Stacey, R. E. Zartman, and I. T. Nkomo (1989). These were the Oquirrh Mountain region, Park City region, Tintic region, and the region around Milford. The lead in feldspars from the main Tertiary intrusive bodies in each of three mining regions in Utah is isotopically similar to the lead in deposits immediately associated with them. These deposits are the largest and also the least radiogenic in each region, whereas the smaller deposits are more radiogenic. Throughout each region the lead in ore appears to be a mixture of various proportions of lead derived from the intrusive magma and a radiogenic lead component derived from the upper crustal rocks through which the mineralizing fluids passed. Linear relationships are exhibited between the lead isotope ratios within each mining region, and these enable the ages of the upper crustal basement rocks to be determined, as shown below:

- Oquirrh Mountains: 1,650±150 m.y.
- Park City (Uinta Mountains): 2,415±50 m.y.
- Tintic region: 2,075±30 m.y.
- Milford region: 1,765±70 m.y.

The first two ages confirm those previously obtained from outcrops of the basement by other methods. The last two are unique since the basement in these regions is completely covered by thousands of feet of later sediments.

**Lead isotopes from Japanese basalts**

The isotopic composition of lead in Japanese primary basalts was found by Mitsunobu Tatsumoto (1990) to gradually decrease in radiogenic character in a traverse from the Pacific Ocean to the Japan Sea, whereas the observed U²³⁸/Pb²⁰⁴ and Th²³²/Pb²⁰⁴ ratios in the basalts increase in the same direction. The lead isotopic variation can be attributed to a past vertical differentiation of the upper mantle, with tholeiite on the Pacific side now being generated at a shallower depth than alkali basalt on the Japan Sea side. The inverse correlation between U²³⁸/Pb²⁰⁴ and Pb²⁰⁶/Pb²⁰⁴ (or between Th²³²/Pb²⁰⁴ and Pb²⁰⁸/Pb²⁰⁴) in such a case
would demand a magma generation process which extracts lead preferentially to uranium and thorium at shallow depths and uranium and thorium preferentially to lead at greater depth. Alternatively, these results can be interpreted in terms of the Pacific oceanic rigid plate being underthrust beneath the island arc. The isotopic variation in basalts across the Japanese island arc could then result from different proportions of oceanic continental material in the partial melt.

**Lead isotopes from some diatremes**

The isotopic composition of lead and the concentrations of lead, uranium, and thorium in the Delegate basic pipes, Australia, and in South African kimberlite pipes were determined by Mitsunobu Tatsumoto. The observed $U^{238}/Pb^{204}$ and $Th^{232}/U^{238}$ of eclogite inclusions in the pipes range from 2.9 to 18.7 and from 3.5 to 5.9, respectively. This result, as well as lead isotopic composition data, suggests that the upper mantle is chemically heterogeneous with regard to these trace elements. Pyrochemically extracted lead from eclogite inclusions in the Australian and South African pipes appear to be different in isotopic composition from lead extracted from the host rock (matrix). These data are consistent with the hypothesis that the eclogitic inclusions in deep-seated pipes are of "accidental" origin and represent upper-mantle materials caught up in the matrix during its intrusion. Lead extracted from a two-pyroxene granulite inclusion in one of the Delegate pipes has an isotopic composition indistinguishable from matrix lead. This observation is consistent either with a "cognate" origin for the granulite inclusion or with a modified "accidental" origin in which the isotopic composition of the original lead in the inclusion has been contaminated by lead from the host magma. Other evidence indicates that a hypothesis of "accidental" origin is preferred.

**STABLE ISOTOPES**

**Deuterium-hydrogen variations in snowpacks**

Irving Friedman and J. R. Meiman (Colorado State University) studied D/H variations in a snowpack, both as the snow accumulated and as it later recrystallized (metamorphism) and finally as the snowpack melted with the advent of warm weather. The original deuterium content of the individual snow layers differed by large amounts (≈2-7 percent), but during metamorphism an isotopic homogenization occurred, and the final composition of the snowpack after metamorphism showed little difference from layer to layer. The melt water released by the snowpack after ablation and melting had a deuterium content equal to that of the integrated content of the original layers. Any loss of material from the pack occurred under conditions where no deuterium fractionation occurred.

**Nature of ore-depositing fluids at Bluebell mine, British Columbia**

R. O. Rye and H. Ohmoto (Princeton University) studied the nature of the hydrothermal fluids responsible for the lead-zinc ores which replaced metamorphosed Cambrian limestones at the Bluebell Mine, British Columbia. Studies of primary fluid inclusions and enclosing host material of late vug calcite and quartz intergrown with sulfides indicate that while $\delta D$ (SMOW) remained constant at $-152 \pm 5$ per mil (equivalent to that of local surface water), $\delta^{18}O$ (SMOW), salinity (NaCl equivalent), and homogenization temperature all decreased gradually during the early stages of deposition from +5 per mil and 10 wt percent at 450°C to $-13$ per mil and 2 wt percent at 300°C. During the final stages of quartz and calcite deposition, temperature rose to 350°C and then decreased to 300°C while $O^{18}$ of the hydrothermal fluid returned to about +5 per mil. These results suggest that the hydrothermal solutions responsible for the vuggy stages of mineralization were largely meteoric in origin, and that the observed variations in $\delta^{18}O$, temperature, and salinity were the result of different degrees of equilibration of meteoric waters with a variety of country rocks.

**$^{34}S/^{32}S$ ratios in minerals from Yellowstone National Park**

The ratio of sulfur isotopes found in sulfur compounds from Yellowstone National Park is close to the ratio of meteoric sulfur and indicates genesis from a well-homogenized, perhaps magmatic, source. Variations of the sulfur isotope ratio are restricted to the fringes of the Yellowstone Plateau and can be best explained by assuming large contributions of sedimentary sulfur. R. O. Rye and Robert Schoen found little or no fractionation of sulfur isotopes during oxidation of the sulfur compounds. This raises questions about the significance of bacteria in the catalysis of these reactions.

**Variations in carbon and oxygen isotope ratios in c-e and host rocks in some Mississippi Valley-type deposits**

W. E. Hall and Irving Friedman (p. C140-C148) investigated the variation of carbon and oxygen isotopic composition in ore and host rock in some Mississippi Valley-type deposits. Systematic decreases were observed in $\delta^{18}O$ and $\delta^{13}C$ in limestone and dolomite.
host rock toward ore. These changes are interpreted as being due to smaller fractionation of these isotopes with increasing temperature toward ore. The calculated $\delta^{18}O$ of the ore fluid during the calcite stage of mineralization for the Upper Mississippi Valley district is +0.4 to -1.6 per mil relative to SMOW. These values are reasonable for the postulated ore fluid of hot oil-field brine that mixed with meteoric water during the late stages of mineralization.

**Structure of water**

By means of the CO$_2$-equilibration technique, J. R. O'Neil and L. H. Adami have determined the temperature dependence and absolute values of the oxygen isotope partition function ratio of liquid water, many at 1°C intervals from -2°C to 85°C. A linear relationship between In $Q_2/\ell$ (H$_2$O) and $T^{-1}$ was obtained that is explicable in terms of the Bigeleisen-Mayer theory of isotopic fractionation. The data are incompatible with conventional multicomponent-mixture models of water because liquid water behaved isotopically as a singly structured homogeneous substance over the entire temperature range studied. A two-species model of water is proposed in which approximately 30 percent of the hydrogen bonds in ice are broken on melting at 0°C and in which this percentage of monomer changes by only a small amount over the entire liquid range. Because of the high precision and the fundamental property determined, the isotopic fractionation technique is particularly well suited to the detection of thermal anomalies. No anomalies were observed, and those previously reported are ascribed to underestimates of experimental error.

**Carbon isotopes in pelites of the Uncompahgre Formation (Precambrian), Needle Mountains, Colo.**

Carbon isotopic ratios and weight percentages of carbon were measured by Fred Barker and Irving Friedman in 15 samples of slate, phyllite, and schist of the 1,500- to 1,600-m.y.-old Uncompahgre Formation of the Needle Mountains, southwestern Colorado. Rocks with less than 1 percent of total carbon, all of which is reduced, have $\delta^{13}C$ values of -23 to -28 per mil, whereas those with 1 to 6.4 percent C have $\delta^{13}C$ values from -29 to -31 per mil. In general, the slates and phyllites contain more carbon and isotopically lighter carbon than do the schists of higher metamorphic rank. Increasing loss of $^{12}C$-enriched methane with increasing intensity of metamorphism is suggested to account for these differences.

**Secondary nature of carbonates in Hawaiian basalt**

Minor carbonate in Hawaiian garnet peridotites and nephelineites were considered to be possibly primary from textural considerations. However, J. R. O'Neil and E. D. Jackson found the $\delta^{18}O$ and $\delta^{13}C$ values of eight samples to be approximately +27 and -16 per mil, respectively. Whole-rock basalts are uniformly about +6 per mil (SMOW$^a$), so these carbonates appear to be low-temperature replacement minerals. The carbon isotope ratios are typical of fresh-water carbonates.

### RADIOACTIVE DISEQUILIBRUM

**Uranium-series dating**

Uranium-series dating was applied by B. J. Szabo to dating fossil bones from the Valsequillo area, Mexico, furnished by Cynthia Irwin-Williams (Eastern New Mexico University) and H. E. Malde. Both Th$^{230}$/U$^{234}$ and Pa$^{231}$/U$^{235}$ activity ratios were measured, and the results of the uranium-series dating of bones together with the C$^{14}$ ages of shells at Caulapan suggest that early man occupied the Valsequillo areas as much as 20,000 years ago. This date is consistent with the hypothesis that man occupied sites in the New World more than 12,000 years ago. The dates from Hueyatlaco and El Horno, however, which imply that man lived in America more than 200,000 years ago, will undoubtedly be rejected by most prehistorians. Such an early date contradicts most presently accepted ideas of the prehistory of both the Old and New Worlds. Nonetheless, the data appear to be internally consistent and should provide stimulus for vigorous study of connections between the Old and New Worlds.

Additional Pleistocene molluscan shells from the marine deposits of southern California were dated by Szabo, using the uranium-series disequilibrium method. The closed-system ages were calculated from the measured Th$^{230}$/U$^{234}$ and Pa$^{231}$/U$^{235}$ activity ratios. It was concluded that shells do not usually form an ideal closed system because of discordancies found between the Th$^{230}$ and Pa$^{231}$ ages of many of the analyzed shell samples. The average open-system ages of the first terrace at San Pedro of the Palos Verdes Hills, the Dume terrace, and terrace C at Point Dume were calculated to be near 85,000, 105,000, and 130,000 years, respectively.

**Uranium distribution studies using neutron-induced fission tracks**

The study of uranium distribution in dated fossil shells and bones by J. R. Dooley, Jr., using the fission-track technique, indicates that uranium is dispersed throughout the samples. White, bleached shell layers may contain only half as much uranium as does the darker organic-rich layers in the same shell. Thin surface layers of bone are also found to be depleted in

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$^a$ SMOW, standard mean ocean water.
uranium. Uranium distribution does not appear to depend on the age or on the relative degree of deviation of the sample from the closed-system requirements, as determined by the measurements of uranium, Th$^{230}$, and Pa$^{231}$ isotopes.

**ADVANCES IN GEOCHEMISTRY**

**Excess radiogenic Ar$^{40}$ in submarine pillow basalts**

G. B. Dalrymple and J. G. Moore (1981) found that submarine pillow basalts dredged from the submerged part of the east rift zone of Kilauea volcano, Hawaii, contain excess radiogenic Ar$^{40}$ and give anomalously high K-Ar ages. Glassy rims of pillows show a systematic increase in radiogenic Ar$^{40}$ with depth, and pillow from a depth of 2,590 m shows a decrease in radiogenic Ar$^{40}$ inward from the pillow rim. The data indicate that the Ar$^{40}$ within the magma was not lost upon eruption, as is normal, probably because the pillows were quenched very quickly under high hydrostatic pressure. This work indicates that many submarine basalts are not suitable for K-Ar dating.

**ISOTOPE HYDROLOGY**

**Carbon isotope and tritium studies in ground-water systems**

Field and laboratory work was completed by William Back, B. B. Hanshaw, Irving Friedman, and Meyer Rubin on a salt-water encroachment study using radiocarbon to date ground water in the vicinity of Hilton Head Island, S.C. In the fresh-water part of the aquifer system, radiocarbon dates have delineated an area of very old ground water (>30,000 years) and an area of very young ground water (<10,000 years), indicating local recharge for the latter water. Additionally, two sources of salt-water contamination to the aquifer system have been identified by means of radiocarbon dating. The two zones of high-chloride waters cannot be differentiated by standard chemical methods; however, by means of radiocarbon studies, it was possible to identify a deep source of very old high-chloride water and another, somewhat more shallow, zone of young saline water. This study indicates the unique capability of radiocarbon dating to ascertain sources of aquifer contaminants. Obviously, this technique is also applicable for determining the source, direction, and rate of movement of manmade contaminants, such as industrial wastes or highly radioactive pollutants.

Samples of ground water from both recharge and nonrecharge parts of the limestone aquifer of central Florida were collected by B. B. Hanshaw, Meyer Rubin, and Irving Friedman and were analyzed for carbon isotope and tritium content. Because tritium has a short half life (12.26 years) compared to C$^{14}$ (5,570 years), water in recharge areas should contain tritium, whereas samples from farther downgradient, in the nonrecharge part of the system, should lack tritium and indicate old radiocarbon ages. The purpose of this study was to establish the validity of a correction equation which utilizes C$^{13}$/C$^{12}$ both to adjust radiocarbon ages by accounting for solution of nonradiogenic limestone and to test for isotopic exchange between the limestone and dissolved carbonate species. Some typical results are shown in the following table:

<table>
<thead>
<tr>
<th>Sample</th>
<th>C$^{14}$ age (years)</th>
<th>ΔC$^{13}$/C$^{12}$ (per mil)</th>
<th>C$^{14}$ age (years ±)</th>
<th>T.U.^1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeki Wachee-11</td>
<td>3,800</td>
<td>-16.3</td>
<td>150 ± 10</td>
<td>103 ± 10</td>
</tr>
<tr>
<td>Lecanto-5</td>
<td>5,800</td>
<td>-13.4</td>
<td>450 ± 36</td>
<td>36 ± 4</td>
</tr>
<tr>
<td>Lecanto-6</td>
<td>5,350</td>
<td>-14.9</td>
<td>1,000 ± 15</td>
<td>15 ± 2</td>
</tr>
<tr>
<td>Frostproof</td>
<td>23,800</td>
<td>-12.3</td>
<td>10,000 ± 0.0</td>
<td>0.0 ± 1</td>
</tr>
<tr>
<td>Holopaw</td>
<td>28,300</td>
<td>-13.9</td>
<td>19,000 ± 0.7</td>
<td>0.7 ± 1</td>
</tr>
<tr>
<td>Arcadia</td>
<td>33,500</td>
<td>-12.3</td>
<td>29,800 ± 0.0</td>
<td>0.0 ± 1</td>
</tr>
</tbody>
</table>

1 C$^{14}$ age adjusted for C$^{13}$ content (±300 years).

The first three wells are in a recharge area and contain tritium. Weeki Wachee-11 had 103 T.U. in 1966; the average tritium content of rainfall in central Florida that year was 114, which indicates that the sample was primarily recent rainfall. The radiocarbon age of this sample is in agreement with tritium results when adjusted for solution of limestone by means of C$^{13}$ content. The other three wells are from the nonrecharge area, contain no tritium, and produce old water according to C$^{14}$ analysis. Comparison of the carbon and tritium analyses shows that the two species corroborate one another and establishes the validity of the C$^{13}$ adjustment equation.

Studies made of the natural tritium content of waters of the Floridan aquifer in the Silver and Rainbow Springs areas of north-central Florida show that tritium can be a useful hydrologic tool for determination of principal recharge areas. According to G. L. Faulkner, correlations made over a 2-year period between the tritium concentrations in periodic rainfall and ground-water samples found that the presence of tritium of recent recharge water in the aquifer could be determined with reasonable assurance. Further, it was found that in localities where the aquifer was known, through surface geologic and test-hole data, to be unconfined and most likely subject to major direct recharge, that very recent modern tritium was present in water of the aquifer. Conversely, at sites were the aquifer is known to be confined, but not great distances from the edge of the aquiclode, practically no tritium was found to be present in the water.
Continuing work by J. D. Gleason, Irving Friedman, and B. B. Hanshaw (p. D248–D250) on the techniques for collection of water samples for radiocarbon dating has indicated that the possibility of isotope fractionation owing to incomplete recovery is inherent in any gas-evolution-sampling procedure. The direct-precipitation method is subject to fractionation problems owing to kinetics. Comparison of isotopic data obtained by gas-evolution and direct-precipitation techniques indicates that, for small-volume water samples, the direct-precipitation method gives correct results when processed properly. Isotopic differences between the two methods are nearly constant and indicate that all past data can be corrected for this error. These results indicate that a water sample may be processed by any technique for radiocarbon dating but that an additional 1-liter sample processed by the direct precipitation of all dissolved carbonate species as SrCO$_3$ is necessary to verify the C$^{13}$/C$^{12}$ of the carbonate.

SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rocks, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. Sedimentology studies in the U.S. Geological Survey are directed toward two ends: (1) solution of water-resources problems, and (2) determination of the genesis of sediments and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many studies in the Geological Survey involving sedimentology are directly applied to other topics such as marine, economic, and engineering geology, and to regional stratigraphic and structural studies; these are reported elsewhere in this volume under their appropriate headings. The sedimentologic studies directed toward the solution of water-resources problems are mainly studies of fluvial sedimentation. The erosion of sediment within river drainage areas, the movement of the sediment through stream channels, and the deposition of the sediment along streams and in other bodies of water is of great economic importance to society even though many of the sedimentation processes are related to or are a part of natural phenomena.

TRANSPORTATION
Vertical mass transfer in open-channel flow

Vertical turbulent mass-transfer coefficients for neutrally buoyant liquid and suspended-sediment particles, and fall velocities of the sediment particles were determined in a large laboratory flume by H. E. Johnson and W. W. Sayre. The turbulent mass-transfer coefficients for the sand particles are represented as the sum of two components that are associated with (1) the tangential component, and (2) the radial or normal component of turbulent velocity fluctuations. The results of the experiment indicate that: (1) the magnitude and distribution of the vertical turbulent mass-transfer coefficient for dye and fine sand are very close to those of the momentum-transfer coefficient; (2) in comparison, the transfer coefficient for medium sand is somewhat less in magnitude, and its distribution is heavily weighted toward the bed; and (3) the fall velocity of sediment particles is slightly greater in turbulent channel flow than in quiescent water.

Step lengths and rest periods of sediment particles in sand-bed channels

Using single radioactive particles, N. S. Grigg made many observations of the step lengths and rest periods of sediment particles moving as bed load over ripple and dune beds in a laboratory flume. The radioactive particles had approximately the same properties as 0.33-mm and 0.45-mm quartz river sand. From the observations, probability distributions for the step length and rest periods were deduced. The moments of the distributions were found to relate to flow conditions in the flume. The gamma distribution appeared to fit the empirical distributions for both step lengths and rest periods. The actual measured rest-period distributions may be approximated closely by distributions derived from temporal bed-form data. Step-length distributions may be predicted from spatial bed-form data.

Hydraulic equivalence of heavy minerals

N. S. Grigg and R. E. Rathbun (p. B77–B80) calculated fall velocities from the drag coefficient-Reynolds number relation and critical shear stresses from Shields' criterion for spheres of quartz, monazite, lead, and gold. The critical shear stress was a function only of specific gravity for grains with nominal diameters less than about 0.1 mm, whereas for larger grains, the critical shear stress was a function of both diameter and specific gravity. The critical shear stress was a function only of specific gravity for fall velocities less than about 2 cm/sec and a function of both specific gravity and fall velocity for larger fall velocities. The critical shear stress became independent of specific gravity and only for fall velocities larger than about 59 cm/sec. These calculations suggest for grains moving in traction, subject to continuous deposition and reentrainment, that equal fall velocity alone should not be a sufficient criterion to assure that grains of different specific gravity will be of equivalent hydraulic value.
Particle size and fall velocity of placer gold particles

C. F. Nordin reported marked differences in size and fall velocity of gold particles from two placer deposits. The coarser gold, from an Alaskan placer deposit, ranged in sieve diameter from 0.177 to 1.410 mm, had a median size \( (d_{50}) \) of 0.64 mm, and the Corey shape factors ranged from 0.06 to 0.18 depending on the sieve class. The coarser grains tended to have the greater shape factors. The finer gold, from a Wyoming placer deposit, varied in sieve diameter from 0.062 to 0.246 mm and had a median size of 0.17 mm. Shape factors were rather constant, being nearly equal to 0.60. The fall-velocity data confirmed that these extremely dense, flat grains followed very closely the relation for drag coefficient, Reynolds number, and shape factor which has been extensively verified for light mineral grains. This data verifies the relation for a specific gravity and shape factors that have apparently not previously been tested.

Rate of transport of sediment particles varying in diameter and specific gravity

A fluorescent-tracer technique was applied by V. C. Kennedy, R. E. Rathbun, and J. K. Culbertson to a study of the rates of transport and dispersion of sediment particles of various diameters and specific gravities for the high-velocity, flat-bed condition in the Rio Grande Conveyance Channel, near San Acacia, N. Mex. Quartz, garnet, monazite, and lead tracer particles having diameters from 0.125 to 1.00 mm were used.

The variation of the centroid velocities of the quartz tracer masses with fall diameter was approximately U-shaped; the minimum velocity occurred for tracer particles having fall diameters comparable to or slightly larger than the median fall diameter of the native bed material. The maximum centroid velocity observed was for the 0.125- to 0.177-mm size class, and the centroid velocity for the 0.707- to 1.00-mm size class was about 76 percent of the maximum velocity. The maximum centroid velocity was about 16 percent of the mean water velocity.

Lateral dispersion of the tracer masses from the point source was represented by the variance of the lateral distribution curves at the sampling cross section. The variance, in general, decreased with increasing fall diameter. The effect of specific gravity on the variance showed no consistent trend.

The sediment-transport rate for quartz particles larger than 0.125 mm calculated from the fluorescent-tracer experiment was 14 percent larger than the transport rate measured at the control. However, the agreement was not as good as suggested because positive and negative errors for the different size classes were compensating.

VARIABILITY OF SEDIMENT LOAD IN STREAMS

Variation in sediment discharge of the Eel River, Calif.

W. M. Brown and J. R. Ritter indicated that the Eel River, Calif., has the highest suspended-sediment yield per square mile of drainage area of any major river in the United States. This yield is estimated at 24 times that of the Mississippi River and about 4½ times that of the Colorado River. Studies of suspended-sediment discharge at Scotia, near the mouth of the Eel, showed a suspended-sediment transport rate of 85,000 tons per day for the period 1958 through 1967. This rate, assumed representative, indicates a sediment yield of about 0.7 foot per 100 years over the entire basin. This figure does not include bedload, and might be biased toward the low side because samples from the deeper parts of the stream, where the suspended-sediment concentrations usually are highest, could not be sampled during periods of very high flow. The unusual flooding of December-January, 1964-65, transported 51 percent of the total suspended-sediment load for the 10-year period in a 22-day period beginning December 20, 1964. Postflood records through 1967 indicate continued high sediment-transport rates well above rates noted in preflood analyses.

The 1964 flood produced notable changes in the channel, which in turn caused a change in a number of characteristic hydraulic relationships in the postflood period. A 10-percent increase in sediment discharge for a given water discharge has been measured at Scotia for the postflood period, and similar increases have occurred at other stations. Analyses of turbidity measurements have led to significant relationships between concentration of suspended sediment and the turbidity of water, especially at higher flows. Regression analyses of these relationships show a high degree of correlation and provide a means of establishing trends related to individual storms, type of material transported, and comparability to other watersheds. These data indicate that turbidity might be a useful parameter in the measurement of suspended sediment at higher flows.

Urbanization and sediment load

The discharge of Colma Creek, a tributary to San Francisco Bay, was affected considerably during 1965-67 by construction activities related to urbanization. Native vegetation and topsoil in large areas were removed during construction of residential and roadway projects so that highly erodible parent material was exposed to winter storms. J. M. Knott reported
that the sediment transported by Colma Creek was 2,940 tons per sq mi in 1966 and 11,200 tons per sq mi in 1967.

**Effect of reclamation of strip-mined area on sediment load**

R. F. Flint reported that during the period of grading, smoothing, and planting operations in Roaring Creek basin at Norton, W. Va., sediment yield in tons per acre-foot of runoff amounted to 325 percent of sediment yield for a 2-year period preceding reclamation work. By contrast, the sediment yield in the adjacent Grassy Run basin, where no reclamation was initiated, showed only a 40-percent increase for the same period.

**VARIABILITY OF SEDIMENT YIELD IN DRAINAGE AREAS**

**Studies in Susquehanna River basin**

On the basis of preliminary analysis of sediment yields in the Susquehanna River basin, K. F. Williams reported the sediment discharges from the major physiographic provinces in the basin range as follows: The glaciated Appalachian Plateau divides into two zones, (1) a low-yield zone extending from the headwaters of the Susquehanna River to Waverly, N.Y., with subbasin sediment discharge ranging from 20 to 200 tons per sq mi per yr, and (2) a high-yield zone extending from the headwaters of the Cohocton River to Waverly, N.Y., with subbasin discharges ranging from 50 to 800 tons per sq mi per yr. In the unglaciated Appalachian Plateau, subbasin sediment discharges range from 66 to 120 tons per sq mi per yr. The subbasin sediment discharges in the Valley and Ridge province range from 58 to 280 tons per sq mi per yr. In the Piedmont, sediment yields in lowlands subbasins range from 100 to 300 tons per sq mi per yr, and in the uplands from 200 to 500 tons per sq mi per yr. The Susquehanna River transports about 3.0 million tons of sediment annually, or about 110 tons per sq mi per yr, past the Harrisburg, Pa., station.

**Sediment data for streams in California, North Carolina, Washington, and Wisconsin**

B. L. Jones and N. L. Hawley summarized California sediment data in the preparation of a hydrologic atlas of stream sediment characteristics. Analysis of suspended-sediment records and reservoir surveys indicates that average annual sediment yields range from less than 100 tons per sq mi in parts of the Sierra Nevada to more than 5,000 tons per sq mi in north coastal California. Average water-weighted-sediment concentrations are equally variable, with less than 300 mg/l in parts of northern and central California, and values in excess of 10,000 mg/l in the arid southern part of the State.

From an interpretation of sediment data from two basins in North Carolina, H. E. Reeder found that the average annual sediment yield for the Yadkin River at Yadkin College, drainage area 2,280 sq mi, is 412 tons per sq mi as compared with a yield of 57 tons per sq mi for the Tar River at Tarboro, drainage area 2,140 sq mi. The Yadkin River basin is in the Piedmont and has steeper land and channel slopes generally finer grained soils than has the Tar River basin which is partly in the Coastal Plain. The differences in these factors appear to cause the higher sediment yield in the Yadkin River basin.

Sediment yields of Wisconsin streams are generally low, but they vary greatly throughout the State, according to a study by S. M. Hindall and R. F. Flint. The average annual sediment yield ranges from 5 to 700 tons per sq mi. The major area of low yield is the forested area of northern Wisconsin, and the areas of high yields are in the hilly terrain of the southwest and the Lake Superior red clay area. Areas of intermediate sediment yield are in the farming areas of central and eastern Wisconsin.

Sediment yield of the Shohomish River basin, Washington, varies widely from year to year and is very sensitive to change in streamflow. A 14-percent increase in streamflow from 1967 to 1968 was accompanied by a 340-percent increase in the suspended-sediment load in the Skykomish River at Monroe and by a 260-percent increase in the suspended sediment load in the Snoqualmie River near Carnation. Estimated suspended-sediment yields from various parts of the basin ranged from 58 to 1,290 tons per sq mi during the 1968 water year.

**Studies of streams draining semiarid lands**

L. M. Shown reported that the Pacific Southwest Inter-Agency Committee method for estimating sediment yields was evaluated in 28 semiarid watershed having sediment-yield records. The correlation coefficient between the estimates and reservoir records of average annual sediment yields was 0.86. The mean for the estimates was 1.2 acre-ft per sq mi, and the mean of the reservoir measurements was 1.65. The estimates, in general, were lower than the records, probably because the author failed to rate the sediment-yield factors high enough in watersheds that had relatively smooth but locally gullied, nonvegetated channels. Also, the method was designed to be used in watersheds that cover more than 10 sq mi; only 3 of the watersheds rated exceeded 10 sq mi, and 20 covered less than 1 sq mi. The
PALEONTOLOGY

fact that the method was designed for larger areas prevented proper evaluation of the factors which cause unit sediment yields to be greater for small watersheds.

It was concluded that the method would give reliable estimates of sediment yields for watersheds of greater than 10 sq mi if the estimator was familiar with runoff and sediment-transport characteristics of the area.

DEPOSITION

Storage in South Carolina lakes

Lakes Marion and Moultrie lie in the Coastal Plain province of South Carolina. Lake Marion, in the Santee River basin, is fed by two major tributaries—the Wateree River and the Congaree River. Lake Moultrie, in the upper reaches of the Cooper River basin, receives water from Lake Marion by means of a diversion canal. Water is discharged from Lake Moultrie to West Branch Cooper River.

T. R. Cummings reported that an analysis of suspended-sediment data obtained during a 2-year period indicates that 800,000 to 900,000 tons of sediment are retained in Lakes Marion and Moultrie each year. The amount of sediment retained is about 80 percent of the sediment inflow to the reservoir system.

Sedimentary structure

Laboratory experiments by E. D. McKee on the development of slumping in sand demonstrated basic differences in structures of strata formed by traction flow and those from true slumping; likewise, criteria have been established for distinguishing between dry-sand, wet-sand, and saturated-sand slumping. All these features are significant in the interpretation of depositional environment in ancient crossbedded sandstones.

GLACIOLOGY

The hydrology of snow and ice is an important phase of water-resource investigations, particularly in the Western States where a large part of the summer runoff is derived from mountain snowpacks and persisting masses of ice. Glaciological studies in the United States are an integral part of a worldwide program designed to provide a better understanding of glacier ice. This water resource constitutes about three-fourths of all the fresh water in the world.

Glacier inventory

The glaciological program of the International Hydrologic Decade includes an inventory of glaciers in the United States, started in 1968 by Austin Post and F. L. Rosselot. The first phase completed includes the identification and classification of 739 glaciers, totaling 266 sq km of area, in the North Cascades of Washington State.

Measurement of glacier mass balances

Mass balances of snow and ice were measured during 1968 at South Cascade Glacier, Washington (W. "Tangborn), Gulkana and Wolverine Glaciers, Alaska (L. R. Mayo), and Maclure Glacier, California (D. R. Scully). At South Cascade Glacier the spring snowpack and total ablation for the year were slightly less than the average for a 10-year period of record. The net balance of \(-0.4 \text{ m}\) represents a loss of approximately \(10^6 \text{ cu m}\) of water equivalent from the glacier.

L. R. Mayo reported that the runoff from Gulkana Glacier basin in interior Alaska is about 10 times greater than that from adjacent forested areas. Of this runoff, 25 percent is from rain, 25 percent is from glacial ice, and 50 percent is from snowmelt. Runoff from the coastal Wolverine Glacier basin is about 2 times that of the interior glacier and about 5 times greater than that from nearby coastal forests. Of this runoff, 20 percent is from rain, 40 percent is from glacial ice, and 40 percent is from snowmelt. In both basins, 10 to 40 percent of the streamflow represents a net loss of glacial ice storage. A continuing net loss of ice shows that the South Cascade, Gulkana, and Wolverine Glaciers are not in equilibrium with today's climate.

Glacier dynamics

Exceptional or catastrophic movements of glaciers, called "surges," are evidenced by distinctive surface features. Aerial reconnaissance of thousands of glaciers by Austin Post has revealed a total of 204 surging glaciers in western North America. Glaciers of all shapes, sizes, and longitudinal profiles can surge, and no unusual ice dams or bedrock constrictions are evident. Surges occur in many different climatic, tectonic, and geologic environments, but in western North America they are limited to certain specific areas. No reason has yet been found for this unusual distribution pattern.

PALEONTOLOGY

Research by paleontologists of the U.S. Geological Survey involves biostratigraphic, paleoecologic, taxonomic, and phylogenetic studies in a wide variety of plant and animal groups. The results of this research are applied to specific geologic problems related to the Survey's program of geologic mapping, resource investigation, and to providing a framework for synthesis of the geologic history of North America and the surrounding oceans. Some of the significant results of pa-
leontological research attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area. Many additional paleontologic determinations carried out by paleontologists of the Geological Survey in cooperation with Survey colleagues are reported under regional studies.

**PALEOZOIC OF THE EASTERN UNITED STATES**

**Worcester Formation fossil plants**

The age of the Worcester Formation in Massachusetts has been a controversial question for many years. On structural grounds geologists have favored a Devonian age, but on floristic character the phylite was regarded as Carboniferous (probably Pottsville) by David White. The problem has been complicated by the fact that the critical fossils examined by White are lost.

A small collection of fossil plants from the "old coal mine" near Worcester, Mass., was submitted to S. H. Mamay by E. S. Grew (Harvard University); another specimen from the same site was referred to Mamay by L. R. Page. Mamay concluded that these plants are definitely post-Devonian, and probably of Pottsville age, thus corroborating White's earlier determination.

**Devonian black-shale algae**

Twenty occurrences of abundant algal remains referred to the genus *Foerstia* in Upper Devonian black shale were studied by J. M. Schopf. All but one are in the Appalachian basin, and all apparently occur in a restricted stratigraphic zone. Their limited range may be related to dependence on a critical near-shore environment for reproduction of the algae. The fossil thalli commonly show egg cells in place, but the eggs seem never to have been released from floating thalli found among the fossils. The reproduction environment for this organism may have included a temporary existence along a rocky coast near the transgressive margin of the sea—a condition that parallels the dependence on environment for reproduction that occurs in the modern algal genus *Sargassum*. Detailed study of the distribution of the fossil algae assigned to the genus *Foerstia*, may provide a means of evaluating tidal currents during a restricted interval of Late Devonian time.

**Kentucky Ordovician bryozoan zones**

O. L. Karklins reported that some Kentucky Ordovician trepostome bryozoans show morphological changes over relatively short stratigraphic intervals that permit delineation of some tentative biostratigraphic zones. Four zones have been differentiated within the Lexington Limestone and Clays Ferry Formation (Middle and Upper Ordovician) in Jessamine, Franklin, and Scott Counties where the boundary between these formations occurs in the upper part of the second zone above the base of the Lexington Limestone.

Upper Ordovician rocks in Mason and Lewis Counties contain three bryozoan zones. The lowest of these zones occurs in the upper Kope and lower Fairview Formations; the middle zone begins in the upper lower Fairview Formation, includes all the Grant Lake Limestone and ranges upward into the lower Bull Fork Formation; the highest of these zones includes the remainder of the Bull Fork Formation.

As far as can be determined the bryozoan zones appear to be independent of local changes in lithology. However, the bryozoan contents of the zones seem to vary regionally. Whether these changes are related to lithology, to geography, or to both, is not presently known.

**Cincinnati arch Ordovician pelecypods**

John Pojeta, Jr., dissolved 15 tons of Ordovician limestone from the tristate area of Ohio, Indiana, and Kentucky that yielded an unrivaled collection of silicified fossils from this classical area. About 100,000 megafossils have been obtained; the biological groups most abundantly represented are brachiopods, pelecypods, bryozoans, gastropods, cephalopods, and corals.

The pelecypod specimens provide unusual opportunities for the study of the morphology, ontogeny, and intraspecific adult variation of 15 species, and significant new information for 30 more species. This wealth of information permits a reorientation of thought on the phylogeny of Early Paleozoic pelecypods.

The relating of the various species to rock types is providing information about those forms which cross facies boundaries and are thus potentially useful time markers. In addition, it has been possible to subdivide the Ordovician rocks of Ohio, Indiana, and Kentucky into five biostratigraphic zones on the basis of suites of genera of pelecypods. This is the first time pelecypods have been used in this manner in the Ordovician.

**PALEOZOIC OF THE WESTERN UNITED STATES**

**Ordovician trilobite faunas**

On the basis of regional studies in Nevada and field work in southwestern Scotland with J. K. Ingham (University of Glasgow), R. J. Ross, Jr., demonstrated the existence of similar trilobite faunas of Whiterock (Middle Ordovician) aspect in both areas. Western Nevada exposures of the *Orthidiella* zone contain trilobites similar to Whiterock trilobites from western Newfoundland. The Scottish faunas are somewhat
younger than those in North America, but all the faunas are geographically related to the transition from miogeosynclinal to eugeosynclinal facies.

**Silurian rugose corals, Great Basin**

C. W. Merriam completed a study of 13 families of rugose corals from Silurian limestones and dolomites of the central and southwestern Great Basin. Coral-bearing Silurian beds of this province consist of two contrasting carbonate facies—the eastern dolomite belt and the intermediate limestone belt. A third major Silurian rock suite—the Pacific border graywacke belt—extends from the western Great Basin to northern California and southeastern Alaska. Five coral zones, lettered A through E in ascending order, are recognized in the Great Basin Silurian. Associated with the corals are ecologically and stratigraphically important dasycladacean algae, principally *Verticillilopora*; these seem to have peaked in coral zone D.

**Late Devonian conodonts from Utah**

A very late Devonian conodont fauna assigned to the lower part of the *Spathognathodus costatus* Zone was found by C. A. Sandberg and R. G. Gutschick near the middle of the type Leatham Formation in the Bear River Range, Utah. The fauna includes the earliest known occurrence of primitive *Gnathodus* and is associated with brachiopods and arenaceous Foraminifera similar to those in the Louisiana Limestone of Missouri. Previously regarded as Mississippian, the Leatham fauna now appears to be unequivocally Devonian. The conodont evidence shows that the Louisiana Limestone brachiopod fauna, which could be as young as latest Devonian or earliest Mississippian in Nevada, Missouri, and Illinois, is long ranging and considerably older in northern Utah and Montana.

**New occurrences of Sly Gap brachiopods**

Characteristic brachiopods of the Sly Gap assemblage, recognized by J. T. Dutro, Jr., from two new areas in Arizona and Nevada, extend its range west and north as far as east-central Nevada. This distinctive brachiopod fauna, known for some years from the Sly Gap Formation of Stevenson of south-central New Mexico, is of late, but not latest Frasnian (Late Devonian) age. The assemblage rarely has been found elsewhere in the Western United States, although some elements are known from the Martin Limestone of central Arizona and the Devils Gate Limestone of central Nevada. The brachiopods of the Sly Gap assemblage show similarities with Frasnian assemblages in western Alberta, particularly from the Mt. Hawk Formation, and appear to be closely limited to an argillaceous and nodular limestone facies.

**Mississippian corals from northwestern Alaska**

Sixteen species of lithostrotionid corals of Meramec age were described by A. K. Armstrong in his study of the Mississippian corals and carbonate facies of the Kogrik Formation (Lisburne Group) in the DeLong Mountains, Brooks Range, northwestern Alaska. Armstrong concludes that the limestones of the Kogrik Formation were deposited in an open marine environment on a subsiding shelf where carbonate deposition and subsidence were near equilibrium.

**First known Early Mississippian beyrichioid ostracodes**

I. G. Sohn described a new species of *Pseudoleperditia*, an ostracode genus originally described from the Touraisian of Russia. The new species is from the Narrow Canyon and lower Mercury Limestones in the Nevada Proving Grounds area, and is represented by growth stages and adults of both sexes; this dimorphism establishes the beyrichiid affinity of *Pseudoleperditia*, and the genus is redefined. This is the first known Early Mississippian representative of the Beyrichicopina, otherwise restricted to the early Paleozoic. This extension of the age range of the dimorphic beyrichiids detracts from their usefulness as guide fossils.

**New paleobotanical developments in Texas and Utah**

In a collection of plant fossils from the top of the Harpersville Formation of former usage (uppermost Pennsylvanian) in Clay County, Tex., S. H. Mamay found excellent compressions of the coenopterid fern genus *Biscalitheca*. This is the youngest known occurrence of the genus, which previously has been reported from only three other localities, one each in Ohio, Kansas and Illinois. *Biscalitheca* has unusual anatomical features that lend themselves well to preservation either as compressions or petrifactions; thus it may prove a useful indicator of Middle to Late Pennsylvanian age.

In collaboration with W. F. Breed (Museum of Northern Arizona), Mamay completed a study of a small collection of Pennsian plants from the Organ Rock Tongue of the Cutler Formation in Monument Valley, Utah. The collection contains elements of the Hermit Shale or *Supaia* flora, as well as a new species of *Protoblechnum*. This is the most northerly known occurrence of the *Supaia* flora, and the presence of *Protoblechnum* lends a distinctly Asiatic aspect to the assemblage.

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62 Stevenson, F. V., 1941, The Devonian Sly Gap formation of New Mexico [abs.]: Oil and Gas Jour., v. 89, no. 47, p. 65.
Mesozoic of the United States

Jurassic ammonites provide definitive age determinations in Pacific coast region

More-accurate age determinations for Middle Jurassic rocks in the Pacific coast region can now be made as the result of R. W. Inlay's work on ammonites from eastern Oregon. Some ammonites of early Middle Jurassic age in eastern Oregon are identical with ammonites of the same age in Alaska and western Europe; these forms provide accurate correlations between those areas, and permit more precise age determinations in the Pacific coast region. The succession of ammonite genera, from Tmetoceras at the base to Teloceras, is remarkably similar to that in Europe and other parts of the world in beds of Aalenian to middle Bajocian age. Exceptions to this include Parabigotites and Zemistephanus, which have been found elsewhere only in British Columbia and Alaska; moreover these forms occur in eastern Oregon in the same stratigraphic successions associated respectively with the genera Oitoites and Teloceras as they do in British Columbia and Alaska. Beds of late Bajocian age are indented by the genera Leptosphinctes, Poecilomorphus, Polyplectites, Spiroceras, Sphaeroceras, and Megasphaeroceras. Most of these are either identical with or closely similar to species in Europe, but Megasphaeroceras has been found elsewhere only in southern Alaska and in the northern part of the western interior region.

Mediterranean affinities of Colorado Graneros and Greenhorn ammonites

W. A. Cobban and R. A. Scott reported that a study of ammonites from the Graneros Shale and Greenhorn Limestone of southeastern Colorado has revealed several large and diversified faunas. About 50 species distributed among 33 genera and subgenera can be recognized. Most of these Colorado ammonites belong to lineages common to the Mediterranean realm.

Ammonites have not been found in the lower two-thirds of the Graneros Shale, but beginning with the Thatcher Limestone Member, four zones of ammonites are present, characterized by different species of Acanthoceras.

The Greenhorn Limestone has the greatest number of genera and species, and one bed of limestone near the base of the Bridge Creek Limestone Member contains at least 12 genera. Many of the Greenhorn species are very closely allied to species from the upper Cenomanian and lower Turonian of southern Europe and northern Africa, whereas other species, such as Neoptychites vertiformis Pervinquière and Choaffaticeras pavillieri Pervinquière, were originally described from the Mediterranean region.

Distinctive Late Cretaceous-Paleocene floral province in southern Rocky Mountains

R. H. Tschudy, in pollen studies of cored material from the Vermejo and Raton Formations of northern New Mexico and southern Colorado, showed that the Late Cretaceous and early Tertiary flora of that region was significantly different from floras of the same ages in the northern Rocky Mountains and in the Mississippi Embayment region; he suggests a separate floral province covering the southern Rocky Mountains to account for the differences in floras. These pollen studies also reveal that the lower 265 feet of the Raton Formation is Late Cretaceous in age, and the upper part is Paleocene in age. Formerly only the lowest 50 feet of the formation had been considered to be of Cretaceous age.

Pollen aids mapping in Jackson Purchase area of Kentucky

During his research studies on Mesozoic and Tertiary pollen, R. H. Tschudy found that characteristic palynomorph suites occur in the Cretaceous and Tertiary strata of the Mississippi Embayment area of Kentucky. These suites are so distinctive for each formation that they can be used as an aid in rapping both outcrop sections and subsurface rocks of the McNairy, Clayton, Wilcox, Clairborne, and Jackson Formations and the Porters Creek Clay, spanning Late Cretaceous through Eocene time.

Cenozoic of the United States

Zonation of Fort Union Formation, North Dakota

Palynological studies by R. H. Tschudy on two well cores have resulted in the establishment of six correlatable levels in the Tongue River and Sentinel Butte Members of the Fort Union Formation (Paleocene) of Morton County, N. Dak. These levels parallel the two lithologic breaks separating the lower and upper parts of the Tongue River from one another and the Tongue River from the Sentinel Butte, respectively.

Eocene pollen floras of Wyoming

According to E. B. Leopold, the pollen flora of the Wind River (lower Eocene) and Tepee Trail (middle and upper Eocene) Formations in Fremont County, Wyo., contain several novel elements. Making their first Tertiary appearances are such forms as Triumphetta, Tilia, Platycarya, and Tsuga, in the Wind River, and Elaeagnus, Juglans, Illex, and Malvaceae in the Tepee Trail. Abundant Platycarya and Lygodium characterize the Wind River flora, whereas sporadic abund-
ance of conifer genera typifies the Tepee Trail flora. Genera of asiatic vascular plants are well represented in both floras. Combination of pollen data with those on the leaf floras provided by H. D. MacGinitie (University of California at Berkeley) shows that both floras contain a mixture of tropical, subtropical, and warm-temperature elements.

Eocene-Oligocene floras and paleoclimates, Gulf of Alaska

During a continuing study of the Tertiary plants of the Gulf of Alaska region J. A. Wolfe found that plants from deposits of late Eocene age are overwhelmingly tropical, both in regard to physiognomic characters and floristic relationships. Fan and feather palms, tropical vines belonging to the Menispermacae and Icacinaceae, and laurels dominate the assemblages. However, in latest Eocene time there was a considerable cooling to temperate conditions, but warming in the Oligocene resulted in assemblages again dominated by laurels.

Stratigraphic distribution of the plants indicates that the lower part of the Kushtaka and Kulkiieth Formations are approximately equivalent and are early late Eocene in age; the upper parts of both formations are of early Oligocene age.

New vertebrate faunas from Colorado

G. E. Lewis found late Miocene and late Pliocene vertebrates in the Dry Union Formation of Chaffee County, Colo. Previous studies had resulted in the identification of only Pliocene (undifferentiated) and early Pliocene forms. The late Miocene assemblage indicates correlation with the Tesuque Formation of the Santa Fe Group, and the late Pliocene assemblage correlates part of the Dry Union with the upper part of the Ogallala Formation of Yuma County, Colo, and with the Ash Hollow Formation of the Ogallala Group of Lugen of Nebraska.

Eocene foraminifers from Adak Island, Alaska

R. L. Pierce found that foraminifers and fish scales from the Finger Bay Volcanics near Andrew Lake, northern Adak Island, Alaska, are of Eocene age rather than the Pennsylvanian or Permian age as had been indicated by the plant *Annualaria stellata* (Schlotheim) Wood found in the same rocks. Such foraminifers as *Uvigerina churchi* Cushman and Siegfus, *Plectofrondicularia packardi* multilineata Cushman and Simonson, *Gyroidina orbicularis planata* Cushman, *Oridorsalis umbonatus* (Reuss), and *Tritylina coleri* Cushman suggest correlation with the Cozy D’Ill Shale of Dibblee, the Kreyenhagen Formation, and the Twobar Shale Member of the San Lorenzo Formation of Brabb of California. (Further implications of the age of the rocks mentioned here are given on p. A52.)

OTHER PALEONTOLOGICAL STUDIES

Stenothecoidea: new class proposed to include primitive Mollusca

The class Stenothecoidea was proposed by E. L. Yochelson (1951) for extinct Cambrian Mollusca which have a bivalved shell but are not Pelecypoda. This and previous studies suggest that the early history of Mollusca was that of a diversification, later followed by a second diversification whose descendants are the extinct mollusks. This new concept of evolution of the phylum Mollusca is supported by other paleontologists who found a similar pattern of development of major groups of Echinodermata through time.

Position of Permian rotational poles

R. E. Grant found that a silicified brachiopod fauna from the Department of Huehuetenango, Guatemala, consists of 17 genera that clearly indicate Leonard age. The fauna contains several genera of exclusively Tethyan, or low-latitude distribution. This adds another control point suggesting that climatic belts in the Permian were parallel to those of today, and consequently that the rotational poles of the earth were very near to the present poles in the Permian.

Evolution of shell-boring habit in snails

An analysis by N. F. Sohl of the fossil history of the predatory shell-boring habit among snails indicates that the habit probably arose first in the Polinicinae (Naticacea) during Late Cretaceous (Cenomanian) time, 100 m.y. ago. In the fossil record the frequency of bored shells increases greatly in rocks of latest Cretaceous age and becomes more widespread during early Tertiary times coincident with the major diversification of the primary groups of boring snails.

The borings in these Cretaceous and Tertiary shells show the same characteristics of preference of penetration in one pelecypod valve rather than the other or in position of the boring site on the shell, that are found in present-day shell assemblages.

Borings in Paleozoic brachiopod shells, 230 to 550 m.y. old, that have previously been attributed to...
tropod predation are herein attributed to other but unknown boring organisms. In part, these borings are not accepted as evidence of Paleozoic gastropod predation because this necessitates (1) postulation of the separate development of a boring habit with its concomitant development of an accessory boring organ in a group whose descendants are all herbivores, and (2) the development of such a habit hundreds of millions of years before the appearance of any relative of present day borers.

Adaptive radiation of Cetacea

In a recently completed study of adaptive radiation in Cenozoic aquatic mammals, F. C. Whitmore, Jr., made a quantitative estimate of the rate at which Cetacea (whales and porpoises) have become adapted to life in the water, and of the time of development of the cetacean population pattern as it existed before inroads by man upon the world-wide community of large whales. The first primitive whales (Archeoceti) are known from about 50 m.y. ago. These animals, although marine, had orthodox mammalian skulls, not yet having developed the blowhole, or nostril on the top of the head. The blowhole appeared with the first Odontoceti (ancestors of the modern porpoises and toothed whales) about 40 m.y. ago. The first diversified cetacean population, including whalebone (baleen) whales, appeared about 25 m.y. ago, and the first large, long-ranging baleen and sperm whales about 15 m.y. ago. The modern large-whale fauna was established by 11 m.y. ago, and about 2 m.y. ago, with the advent of Pleistocene climatic belts, Arctic and Antarctic races of large whales developed.

Cretaceous ostracode zones from Jamaica

A study by J. E. Hazel of over 100 species of ostracodes from 50 samples collected from shales and limestones of Maestrichtian (Late Cretaceous) age, which crop out in the inliers of central and western Jamaica, has resulted in the establishment of three ostracode zones and three subzones in the so-called Titanosarcolites sequence. The Titanosarcolites-bearing limestones exposed along the railroad between Cambridge and Catadupa in the Marchmont inlier correlate with the Maldon Formation of the Maldon inlier and with the middle part of the Guinea Corn Formation of the Central inlier. However, the limestones containing Titanosarcolites in the Jerusalem Mountain inlier to the west are younger and appear to represent a return, after a volcanic episode, to conditions similar to those that existed during deposition of the Maldon and Guinea Corn Formations and the limestones between Cambridge and Catadupa.

JOIDES drilling and Oligocene correlation

The first extensive drilling and coring of ocean sediment that was deposited far from continents is being done by the JOIDES (Joint Oceanographic Institutions Deep Earth Sampling Program) Deep Sea Drilling Project. Initial examination of calcareous nannoplankton from the cores by J. D. Bukry indicates that many taxa known from shelf deposits are missing in deep-ocean sediment of the same age. For example, lower Oligocene sediment cored east of the Bahama Platform in DSDP hole 5 (lat 24°43.6' N., long 73°38.5' W., water depth 5,354 m, subbottom depth 4 m) contains a diverse assemblage that is readily correlated with those of the lower Oligocene of the Gulf Coastal Plain (Red Bluff Clay and Vicksburg Group) and the Blake Plateau (JOIDES cores J-3 and J-4) by the concurrent ranges of such species as Bravusphaera rosa Levin and Joerger, Helicoportunospa Sphaera compacta (Bramlette and Wilcoxon), Pteriuchelina joyeas Bukry and Bramlette, and Zygrhahblithus bijnatus (Deflandre); however, these species are notably missing from the early Oligocene nannoplankton assemblage on the west flank of the Mid-Atlantic Ridge in DSDP hole 10 (lat 32°51.7' N., long 52°12.9' W., water depth 4,682 m, subbottom depth 54 to 77 m). The common early Oligocene species on the Mid-Atlantic Ridge are Coccolithus bisectus Hay, Mol ler, and Wade; C. eopelagicus Bramlette and Riedel; Cyclococcolithus lusitanicus (Black); C. neogammation Bramlette and Wilcoxon; Discoaster tani tani Bramlette and Riedel; Reticulofenestra umbilica (Levin); and Sphenolithus pseudoradialis Bramlette and Wilcoxon. These open-ocean species are also present in the Bahamas Platform, Blake Plateau, and Gulf Coastal Plain. It is suggested that the absence of a diverse group of species from the most distinctly oceanic locality was mainly determined by factors of ecology and preservation. The absence of Zygrhahblithus bijnatus (Deflandre) and other very delicately constructed holococcoliths that are quite common at some Gulf Coast localities may also be related specifically to burial and preservation factors. Through comparison of nannoplankton assemblages from these four areas, which represent a sequence from substantial to negligible influence by near-shore environment factors, the most widespread and therefore most stratigraphically useful species can be identified. The concurrent ranges of the species cited for DSDP hole 10 can be applied in all four areas to indicate an early Oligocene age; hence their value as guide fossils seems confirmed.
Diversity of Foraminifera in western North Atlantic Ocean

The living foraminiferal fauna in the western North Atlantic was found by T. G. Gibson to have the highest diversity, both in terms of numbers of species and species equitability (equality of species proportions in an assemblage), in abyssal depths of greater than 2,500 m. The data contradict the popular concept of greater diversity in the shelf regions. Large population samples from 84 stations were used in the study. Three peaks in diversity are found, one, in terms of equitability, at 35 to 45 m, the second at 100 to 200 m, and the highest at greater than 2,500 m. These patterns are being used to interpret paleoenvironments in Mesozoic and Cenozoic strata, particularly phosphatic beds, where lack of modern faunal counterparts makes direct comparison difficult.

GEOMORPHOLOGY

Origin of Ohio River

The headwaters of the preglacial Salt River of Kentucky are now believed to have been incorporated in the headwater reaches of the preglacial Ohio drainage basin, according to regional reconnaissance studies by L. L. Ray. The first glaciation, the Nebraskan, disrupted the preglacial Teays-Mahomet drainage; glacially ponded streams overtopped and breached a divide near Manchester, Ohio, and another near Madison, Ind. Streams formerly tributary to the Teays-Mahomet became part of the Salt River drainage west of the divide at Madison. Below Louisville, Ky., the newly established Ohio River followed the course of the main stem of the preglacial Salt River.

Gully erosion on islands in the western Pacific

Gully erosion produces small pedimentalike surfaces at various altitudes. The altitude of such surfaces may be independent of sea level, according to Gilbert Corwin, and these forms should not be used as indicators of relative changes in position of land and sea.

Ventifacts near Grand Sable dunes, Michigan

Ventifacts on the edges of dunes on south shore of Lake Superior near Grand Marais are of two contrasting types. Faceted ventifacts and rounded forms with circular depressions are reported by M. J. Grolier. Facets result from sandblasting. The rounded forms, of graywacke, sandstone, and limestone, are water-worn pebbles with depressions enlarged, if not initiated, by sand scouring and perhaps by solution.

Hydraulic geometry of streams

A least-squares solution for the exact description of the hydraulic geometry of rivers was devised by N. C. Matalas and E. J. Gilroy and used for the first time by C. W. Carlston. Downstream changes in hydraulic geometry of rivers is a power function for which a least-squares computer solution shows the mean exponent for 10 river basins to be: width = 0.461, depth = 0.383 and velocity = 0.155.

An analysis of a large number of individual streams by Carlston shows that: (1) successively higher order streams tend to become progressively deeper resulting in lower roughness and higher velocity, (2) the number of streams with a downstream increase in velocity is balanced by an equal number of streams with a constant velocity or a downstream decrease in velocity, (3) the modal exponent for velocity is 0.0 (constant), (4) four rhodamine dye tests over long distances (190–806 miles) on three rivers have demonstrated constant downstream velocity.

There is, therefore, good evidence that the most common condition for long segments of rivers is a nearly constant downstream velocity, and L. B. Leopold's excellent evidence that this constant velocity is the rule for flood discharges over a wide range in discharge.

Very large rivers such as the Mississippi accommodate downriver increase in discharge primarily through increase in depth and secondarily through increase in velocity, whereas lesser rivers generally accommodate the downriver increase in discharge principally through increase in width, and the velocity exponent ranks third.

Slope-discharge relations of eight rivers

Graphical correlation and computation of the relation of slope to discharge was made for eight rivers in the United States by C. W. Carlston (10294). The power relations or exponents for slope varying with discharge for the Red River of Louisiana and the Arkansas River were −0.55 and −0.50, respectively, and correlation was high. The lower 1,800 miles of the Missouri has a nearly constant slope (low amount of variation) so that for the greater part of the Missouri the exponent was 0.0. For the Tennessee–North Fork Holston River, correlation was high and the exponent was −0.62. The Delaware River had an exponent of −0.93. No linear correlation between slope and discharge could be found for the Ohio River, the Susquehanna River, and the Alabama-Coosa River and headwaters. The sample was too small to permit definite conclusions, but there are indications that this log-log graphical correlation and computation may be of use in determining the degree of dynamic equilibrium or the degree of approach to a graded condition.
Changes in channel morphology

An unusually severe storm (12 to 14 inches of precipitation) occurred from December 3 to 8, 1966, along the north rim of the Grand Canyon, Ariz. The storm runoff, according to M. E. Cooley and B. N. Aldridge, caused renewed arroyo cutting in Outlet Canyon—which flows into Phantom Creek, a tributary of Bright Angel Creek—and in short reaches of two other streams draining the Kaibab Plateau. Before the storm, the arroyo along the stream in Outlet Canyon had been healed by a dense stand of grass. The renewed arroyo cutting resulted from the formation of scours and from the integration of the scours by upstream, sideward, and downstream extensions of the scours caused by turbulent flow. The renewed cutting deepened the prestorm arroyo by 1 to 2 feet over about 75 percent of the old channel floor. The flood erosion left about 50 percent of the prestorm channel sides intact. Traveling upstream from the head of continuous cutting, the scours progressively become smaller and spaced farther apart. The peak flow along this stream, determined from a slope-area measurement, was 414 cfs from a drainage area of 7.4 sq mi.

J. F. Daniel, in studying Indiana streams, found that the process of channel movement in a meander system involves an increasing path length and rotation of the loops. Either or both forms of movement may occur, depending on the boundary conditions of the loop. Direction of movement is related to the force required to change flow direction, and rate of movement is related to discharge and grain size of the bed and banks.

Hydraulics of overland flow on hillslopes

W. W. Emmett found that overland flow resulting from rainfall on natural hillslopes responds to a downslope increase in discharge by increasing its depth and velocity. Depth absorbs about two-thirds of the increase in discharge; velocity absorbs about one-third. For straight slope segments investigated in the field, resistance to flow remains nearly constant in the downslope direction. The comparison of field data to laboratory data shows general agreement, but illustrates the extreme influence of vegetation and topographic irregularities on resistance to flow over natural hillslopes. Values of resistance to flow expressed as Manning's n were as high as 1.0 and averaged about 0.5, roughly corresponding to a Darcy-Weisbach friction factor of 100.

Although the ground surface over most of the test plot areas was covered by surface detention during overland flow, most runoff occurred in several laterally spaced concentrations of flow. These concentrations of flow are capable of eroding and transporting sediments. Despite surface erosion by the runoff, no rilling was observed to have developed.

Effects of glacial-lake wave erosion of drumlins in New York

Geohydrologic studies in the Lake Ontario plain by W. A. Hobbs, Jr., revealed many flat-topped drumlins with sand and gravel aprons. The tops of the drumlins were leveled by waves of glacial Lake Iroquois (predecessor to Lake Ontario). The wave action removed all rock particles but the boulders, which are now concentrated on the flat surface of the drumlins. The sand and gravel were deposited as stratified aprons, and finer silt and clay particles were deposited even farther from the drumlins in deeper water. The fact that most aprons are found on the eastern slopes of the drumlins indicates that the erosive waves came predominantly from the west. The poor sorting of grains making up individual strata reflects the variation in wave intensity.

Drumlin aprons are of economic importance as sources of ground water and sand and gravel.

Geomorphic studies in Puerto Rico

In preliminary geomorphic study of the karst area in the northern part of Puerto Rico, E. V. Giusti found evidence of widespread stream capture. Although the formations dip gently to the north, the topographic surface slopes to the northeast. The main streams, which receive major tributaries from the southwest only, flow northwestward, whereas the tributaries flow northeastern, more in line with the topographic slope. These discrepancies are tentatively ascribed to eastward tilting of the entire Puerto Rican platform in Pleistocene time.

The development of sinks, as defined by depression contours on topographic maps, appears to be at a maximum where the local relief is about 80 m, covering about half the land surface. Where the relief is greater there is a decrease in sink development.

Rates of chemical denudation

In attempting to compare rates of chemical denudation on the western slope of the Sierra Nevada with chemical denudation rates from other areas, R. J. Janda found that past computations of chemical denudation rates have exaggerated by 2.5 to 5 times the significance of this process because the computations were based upon total dissolved loads. Chemical analyses of waters draining crystalline silicate rocks indicate that commonly 60 to 80 percent of the total dissolved solids are HCO₃⁻, SO₄²⁻, Cl⁻ and NO₃⁻ that cannot be derived from the underlying rock; instead these ions are
derived either directly from the atmosphere or from atmosphere-biosphere interactions.

**GROUND-WATER HYDROLOGY**

Research on ground water continues to cover a considerable range of subject matter reflecting the recognized need to define both broad and specific principles and processes of ground-water systems. Salty and freshwater relationships, model analysis, carbonate-rock hydrology, and techniques of artificial recharge for water-supply management are among the principal topics receiving attention. Summarized below are selected examples of research investigations in ground water, with principal attention to current field studies.

**Artificial recharge**

Pilot experiments in artificial recharge conducted at Bay Park, Long Island, N.Y., using tertiary-treated sewage-plant effluents for recharge water, have shown little deterioration in well capacity. The maximum injection rate has been 350 gpm, sustained for 50 hours. John Vecchioli, in charge of the research, reported that redevelopment by pumping after each recharge test restores most of the well capacity lost during injection. Injection of recharge water is through a well cased with fiberglass and finished with gravel-packed, 16-inch diameter, stainless-steel screen. The screen is set at a depth of 420 to 480 feet in the Magothy Formation (Upper Cretaceous).

B. L. Foxworthy reported successful injection of water into a basalt aquifer through a well at Salem Heights, Oreg. Periodic comparisons of the specific capacity of the well (rate of injection divided by buildup) provided early warning of incipient clogging of the aquifer. Air bubbles in the recharge water were the major cause of clogging, and were adequately removed by intermittent pumping after injection was stopped. Release of the air dissolved in the recharge water was minimized by injecting water through a turbine pump at a rate great enough to maintain back pressure on the water in the pump column. It has been found that water from uncased wells in the basalt aquifer contains unusually large amounts of dissolved oxygen. Ground water from perched aquifers in the basalt cascades down the wells and is believed to absorb and dissolve air before recharging the lower aquifer. The oxygen content of the native ground water diminished as the test well was pumped, supporting this conclusion as to the source of the oxygen.

An entirely different technique of artificial recharge—surface spreading—was utilized in Walnut Creek watershed, in central Kansas, to replenish ground water at a rate of about 0.5 acre-ft per day per acre. The water was pumped into a pond formed by a semicircular dam enclosing about 0.8 acre on an alluvial slope covered with native grass. The pond holds about 2 acre-feet of water with an average depth of 2.2 feet. The water was successfully recharged through approximately 45 feet of clayey to sandy silt to the underlying sand and gravel beds.

A case of unplanned artificial recharge of ground water in Nebraska was investigated by M. J. Ellis. Infiltration of surface water, imported into Gosper, Kearney, and Phelps Counties for irrigation applications, has caused a pronounced rise in the water table. Maximum buildup of ground water has occurred near the main irrigation-supply canals, where 90-foot rises since 1938 have been recorded. The mound is more than 50 feet in an area of about 200 sq mi. An estimated 6 million acre-feet of water have been added to ground-water storage since the first use of surface water for irrigation in the area.

**Loading effects simulate natural recharge**

A 5,700-acre tailings pond near Magna, Utah, on the floor of the Jordan Valley, has caused cessation of evapotranspiration of ground water from the area covered by the pond and an apparent recharge effect from loading of the ground-water reservoir, according to A. G. Hely, R. W. Mower, and C. A. Horr. The layer of saturated mine tailings, 90 to 100 feet thick, is supported both by the reservoir skeleton, which is unconsolidated valley fill, and by the ground water. A great weight, about 1.7 billion tons of tailings, is compacting the skeleton and “wringing” water out of the beds. Expelled ground water moves laterally through beds of sand and gravel beneath the tailings pond to adjacent parts of the ground-water reservoir. Water levels near the tailings pond remained nearly stable during a period when water levels in other parts of the reservoir were declining. In this manner, the artificial loading has produced, for a time at least, the same effect as recharge.

**Hydrology of carbonate rocks**

V. T. Stringsfield's research on the hydrology of carbonate-rock terranes is currently involved with carbonate-aquifer characteristics and the manner of development of karst features. Four carbonate-aquifer systems are among the most productive ground-water sources in the United States. These are: (1) the shallow aquifer (Biscayne aquifer of Tertiary and Quaternary age) in southeastern Florida, (2) the principal artesian aquifer of Tertiary age, known as the Floridan aquifer in Florida, (3) the Edwards Limestone aquifer...
in the Edwards Plateau, Tex., and (4) the artesian aquifer of Permian age in the Roswell artesian basin in southeastern New Mexico. Although large parts of three of these systems are artesian, studies to date indicate that the permeability is chiefly secondary, having developed principally in the upper part of the zone of saturation under water-table conditions and as the water table rose or fell. Stringfield attributes a large part of the secondary permeability to buried karst in which the permeability was not destroyed by the burial process.

H. G. Jeffery and G. L. Feder obtained interesting results from investigations of the deep, widespread circulatory system carrying ground water in the dolomite terrane of the southern Ozark region. Dye introduced in a losing reach of a tributary of the Eleven Point River traveled underground 18½ miles to the north-east beneath a major topographic divide and reappeared at Big Spring in the Current River valley. In another test, daily conductance measurements of ground water taken from a well 1,500 feet deep and cemented to 1,000 feet, producing from the Eminence and Potosi Dolomites, showed a notable fluctuation in conductance, ranging between 380 and 470 μhos. Daily conductance in another well, similar except that it is cased only to 450 feet because weathered rock did not extend as deep, showed no such fluctuation. More vigorous ground-water circulation in the first instance is suggested, but additional data are required for interpretation.

**Hydrology of crystalline rocks**

G. E. Siple compared the hydraulic head in saprolite with that in adjacent underlying fresh rock and with that in the overburden of coastal plain sediments. Wells drilled in the buried crystalline rock (Carolina slate belt), in the Wateree River basin, South Carolina, a short distance southeast of the Fall Line, reveal that water in fracture zones in the fresh rock at depths of 200 feet or more has continuity of head with water in the overlying saprolite at depths of only 35 to 50 feet below the land surface. Comparison of water levels in wells screened in the coastal plain sediments with the head in the underlying crystalline rocks shows the latter to be higher in some instances than the head in the sediments. Siple postulates that continuity of head in the confining bed of saprolite and the crystalline rock beneath the coastal plain deposits is suggestive that the process of saprolitization was not restricted to pre-Cretaceous time and may still be active.

**Model studies**

Models are useful not only for hydrologic analysis and prediction of cause-and-effect relationships, but also for testing preliminary concepts of how hydraulic systems operate. In modeling studies of ground water in Orange County, Calif., the first hypothesis of the hydrologic system of the coastal plain portion of the county was found to be incorrect, as revealed in the first approximation of an electric analog model analysis by W. F. Hardt and E. H. Cordes. This first trial and the lack of close verification demonstrate the need for better information on (1) the amount of deep percolation in the artesian zone, (2) vertical permeability coefficients, and (3) change in aquifer storage with time. The flow system in Orange County was demonstrated to be more complex than originally thought, and the initial model analysis has shown the kinds of additional data required.

Data assembly and analysis are underway in Long Island in preparation for islandwide model studies of the principal aquifers. N. E. McClymonds is completing a study of data on Long Island's aquifers, including preparation of a series of permeability and transmissivity maps. Average transmissivities determined from the maps are 200,000 gpd per ft for the upper glacial aquifer, 105,000 gpd per ft for the Jameco aquifer, 240,000 gpd per ft for the Magothy aquifer, and 85,000 gpd per ft for the Lloyd aquifer. McClymonds and O. L. Franke are preparing to construct a 2-layer electric analog model of the ground-water reservoir of Long Island, including Kings, Queens, and Nassau Counties and most of Suffolk County.

The current annual pumpage of about 120,000 acre-feet of ground water in Avra Valley, Ariz., is depleting the area's ground-water supply. Water levels have declined as much as 100 feet since 1940. With the aid of electric analog analysis, Otto Moosburner calculated that additional declines to the year 1985 will be small (less than 20 feet) in some parts of the valley but as much as 100 feet in others, provided the pumping rates do not change.

**Corrosion studies**

On the basis of study of corrosion and encrustation problems at U.S. Air Force sites in Alaska, H. L. Heyward classified the State's ground-water supplies in two categories with respect to chemical quality—very soft water containing dissolved oxygen, and hard water containing no dissolved oxygen. The soft oxygenated water severely corrodes both mild steel and red brass in well casings, screens, distribution systems, and other water-supply equipment. The hard water may or may not corrode mild steel, apparently depending upon its electrolytic properties, degree of saturation with calcite and various iron phases, temperature, and content of neutral salts. Alloys of aluminum, copper,
or stainless steel are not affected by either type of water.

Coastal-plain aquifers

Studies by H. J. Hansen of the coastal plain sediments of Maryland, based chiefly on geophysical logs, transmissivity values, and chemical analyses of water, indicate a cyclic repetition of three major environments of sedimentation (lithotopes)—nonmarine, fluvimarine, and marine. The results suggest that transmissivity trends in the nonmarine lithotopes are commonly parallel to the dip and that the transmissivity trends in the marine lithotopes are commonly parallel to the strike of the sediments.

Analysis of subsurface data on coastal plain sediments to the north in New Jersey, by H. E. Gill, indicates that the fluvial sediments of the Potomac Group and Raritan Formation were deposited as ancestral channel fill and overbank deposits in directions roughly perpendicular to the present course of the Delaware River southwest of Trenton. Preparing piezometric maps of the area indicate that these channel-fill areas function as natural drains for the Potomac-Raritan system. The maps indicate also a significant vertical leakage to the system from the overlying Englishtown and Mt. Laurel aquifers.

Fresh and salty ground water in coastal areas

Occurrence of saline ground water beneath the lower delta of the Mississippi River was analyzed by P. H. Jones. The entrenched valley of the river (of late Wisconsin age), now filled to more than half its depth by permeable sand and gravel, is an area beneath which saline water at shallow depths extends inland from the modern shoreline farther than anywhere else in the northern Gulf of Mexico basin. Gulfward from Baton Rouge, La., marine clay overlies gravel fill and the alluvial cone beneath the Continental Shelf. In the concept expressed by the investigator, the Holocene deltas overriding this marine-clay bed have squeezed its connate salty water into the underlying gravel bed. In his view, continued delta growth is causing further inland salt-water encroachment.

Water-level monitoring of a water-table aquifer on a small island in the Charleston, S.C., harbor shows discrepancies between the observed position of the fresh-water–salt-water interface and that calculated by use of the Ghyben-Herzberg formula. According to G. E. Siple, the apparently anomalous situation applies both for steady-state and transient conditions. The heterogeneity and low permeability of the aquifer materials make hydraulic analysis by pumping-test methods difficult. Disagreement with the classical concept of fresh-water–salt-water relations has been reported in other studies, and local hydrodynamics are generally involved in the explanation of the apparent discrepancy. Several years ago J. E. Upson identified apparent departures from the normal Ghyben-Herzberg relation in certain northern Atlantic coastal areas of the United States. He suggested the explanation that hydrodynamic adjustment of the position of the interface has been rapid enough to keep pace with the changes in sea level during recent geologic time. Upson concluded that the position of the salt-water–fresh-water interface in a particular aquifer is controlled chiefly by the flow pattern in the aquifer and the position of discharge areas.

At the municipal well field, Cocos, Fla., water samples from a tube, especially designed and emplaced to sample the Floridan aquifer at depths of 1,344 to 1,357 feet below land surface, revealed a steady increase in chloride content (from 720 to 850 mg/l) during the period 1967–68. Despite the increasing chloride, the water level in this tube does not appear to respond to pumping in a nearby supply well at the same depth. A similar tube sampling the Floridan aquifer at shallower depth, 1,195 to 1,237 feet, has not shown increase in chloride, and the important producing zone above, between 250 and 761 feet below the land surface, is not considered to be in early danger of contamination. T. W. investigators, W. F. Lichtler and C. H. Tibbals, state that the shallow unconsolidated material overlying the Floridan aquifer may prove to be an important aquifer, especially since it appears to be hydraulically insulated from the present producing zones by clay layers and, hence, protected from the advance of salty ground water.

Controlled pumping rates and high aquifer transmissivity minimized salt-water intrusion in the Floridan aquifer at Clearwater, Fla. However, R. N. Cherry observed that the long-range development of ground water in that area will entail effective utilization of water in the unconsolidated aquifer as well. Most of the Clearwater peninsula is underlain by saline water at depths greater than 250 feet. Similar investigations by Cherry indicate that in the Dunedin area of Florida, the shallow unconsolidated aquifer and the Floridan aquifer are separated by a clay layer, which will serve to minimize shallow contamination. In Dunedin, salt-water intrusion has been held minimal by positioning wells far apart, by controlling pumping, and by reaping the hydraulic benefits that accrue from the high transmissivity of the aquifer.

Hydrology of clay

Laboratory values of the diffusivity of a confining layer, determined by R. G. Wolff, are in reasonable
agreement with those obtained in field tests by the researcher. Efforts are being made to improve the agreement by additional laboratory studies. At the field test site, observations of surface strains around a pumping well show a correlation between the strain pattern and anomalous observed pressure changes in the confining layer.

**Tracing ground water**

J. M. Cahill and Akio Ogata caution on the need to evaluate tracer attenuation or deterioration with time when used in tests lasting days or weeks or longer. Both salt and dye tracers are employed in their research on quantitative analysis of two-fluid flow in porous media, utilizing hydraulic models. The movement of salt is determined by conductivity probes inserted in the models. A photocell positioned externally to measure light transmission through the models is used to track movement of the dyes. Correlation of data obtained by the two methods has proven negative so far. Although for short tests the two tracers seem to move at the same rate, in tests nearly a week in duration large discrepancies were observed. This is probably due to characteristic fading of the dye and possibly to difference in the absorption rate.

A series of flow-meter measurements in a deep well in South Dakota demonstrated that water moves from one permeable zone in the Dakota Sandstone to other zones through the well. The tests were run by D. G. Jorgensen and E. F. LeRoux in a well perforated in four permeable zones in the Dakota Sandstone. With the well shut in, upward movement of water was detected between the deepest perforated zone and those above. Two other flow traverses were run, one with the well flowing 136 gpm and the other with a flow of 268 gpm. These tests indicated that practically all the water discharged at the surface was derived from the deepest perforated zone. This information suggests that the common practice of perforating wells in all the permeable zones of the Dakota Sandstone may be undesirable in places.

**Response of wells and aquifers to explosions**

At Amargosa Tracer Site in central Nevada, near the Nevada Test Site of the U.S. Atomic Energy Commission, a pair of similarly constructed wells, except that one is sealed with inflatable packers and the other is left open, have been used to monitor nuclear detonations. Total pressure-response amplitude in the sealed well is approximately two orders of magnitude greater than that in the open well. In addition, the confined well is sensitive to seismic waves of much higher frequency. These results of work by W. W. Dudley, Jr., confirm the theoretical dependency of well response upon well construction, aquifer characteristics and the nature of the seismic waves.

Sustained high pore pressures have been observed in deep wells situated near nuclear explosions at the Nevada Test Site. Shallow wells show much more rapid decay of high pore pressures. One deep observation well 914 m from ground zero of a nuclear test explosion had an anomalously high water level one year after the event. The reasons for these anomalies are being investigated.

*Note.*—For discussion of ground-water hydrology in which computer applications were used, see section entitled "Computer applications—ground water," pages A155–A156.

**SURFACE-WATER HYDROLOGY**

The ultimate objective of research on the occurrence and movement of surface water is to provide methodology for the measurement of flow, the prediction of time of travel and dispersal rate of solids and solutes in streams, and the development of deterministic and statistical models of the variation of streamflow in time and space under both natural and manmade conditions.

**Mechanics of flow**

As the amount of water that can be carried by a stream channel varies inversely with the roughness of the channel, research is being continued on evaluating Manning's $n$, a coefficient of roughness.

From observations made during the first year after construction of an earthen canal for Hanging Moss Creek at Jackson, in central Mississippi, K. V. Wilson (r0298) found that Manning's $n$ at a 5½-foot depth of flow changed from 0.025 in March 1964 to 0.05 in October. He attributes this twofold increase in roughness to the small willows, weeds, and grasses that grew during the summer and concludes that the carrying capacity of earthen channels may be greatly reduced as a result of only 1 year's growth of vegetation.

From field data collected on the Rio Grandes conveyance channel near Bernardo in central New Mexico, J. K. Culbertson and C. H. Scott observed that a distinct change in bed configuration and in Manning's $n$ could be associated with the fall velocity of the median-diameter bed material. For fall velocities less than about 0.070 fps, the bed was always plane, with $n$ values from 0.013 to 0.017, and for fall velocities greater than about 0.080 fps, the bed was always dunes, with $n$ values from 0.022 to 0.034. The median diameter of bed material in the conveyance channel for all observations ranged from 0.16 to 0.32 mm and averaged 0.21 mm.
Dispersion in open-channel flow

Dispersion of contaminants introduced into a flowing stream either intentionally or accidentally is of great concern to downstream water users and is the subject of continuing research.

In a study of the distribution of temperature in a water system, Nobuhiro Yotsukura found that an explicit numerical method gave solutions to the heat-balance equation that were within reasonable agreement with analytical solutions and with results of dye-distribution observations. In computing the dissipation aspects of the numerical solution, he found that the coefficients in a formula resulting from work by Harbeck vary with the time interval when the interval used is less than a day.

Using data from a wide variety of streams for which time-of-travel measurements have been made by injecting Rhodamine B dye, J. F. Wilson, Jr., (r0297) related the amount of dye required for slug injection to the volume of flowing water in a stream reach. He suggests how the general formula he developed should be modified for low-flow or low-velocity measurements and for use with Rhodamine WT dye.

By using a reaeration coefficient relation proposed by Langbein and Durum and cross-section data obtained by field surveys, T. J. Buchanan (r0293) computed reaeration coefficients for 18 subreaches in 16.8 miles of river system in northeastern New Jersey for discharges equal to that at the 50-, 80-, and 90-percent discharge duration point in each subreach. Although no data were obtained to check the coefficients computed in this inexpensive way, the results are consistent with what might be expected and are probably better than those derived from laboratory studies or from coefficients computed for a different river system.

Flood risk

The problem of setting flood insurance rates requires knowledge of flood-prone areas and of the risk of flooding for various structures in the area. To help in the development of procedures for setting flood insurance rates, H. H. Barnes, Jr. (r0296) defined the inundation limits for a 100-year flood for the Leaf and Bowie Rivers in the vicinity of Hattiesburg, in southeastern Mississippi, and developed flood profiles for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods. The flood-frequency analysis was based on records of flood peaks at three gaging stations in the Hattiesburg area. The profiles were computed using standard-step backwater techniques based on channel and flood-plain conditions observed in November 1958. Each of 2,526 homes within the limits of the 100-year-flood zone was identified in terms of address, number of family units, type of construction, number of floor levels, height of first floor, and stationing along the flood-profile reference line. The study was made as part of a joint effort with other Federal agencies to determine probable flood risks and damage rates in a pilot area.

Peak-flow simulation and analysis

The problem of predicting flood-frequency characteristics at sites with only a short record or no record of flood peaks demands that research be continued into rainfall-runoff relations, methods of synthesizing peak flows, and the use of statistical principles that pertain to the occurrence of flood peaks.

A simplified mathematical model of the surface-runoff response to storm rainfall was developed and programmed for digital computer solution by D. R. Dawdy, R. W. Lichty, and J. M. Bergmann. The model has been tested using a few selected small stream basins in California, Iowa, Mississippi, Missouri, North Carolina, and Virginia. A measure of the model accuracy, which includes both model and input data errors, is the standard deviation of the residuals of computed peaks from observed peaks. According to H. G. Golden, the standard deviations of the residuals for the basins tested ranged from 15 to 50 percent. The model and long-term rainfall records will be used to extend short flood records, thus, providing improved estimates of peak probabilities on small streams.

By simulating peak flow from observed precipitation on a 9.7-sq-mi area in the Santa Anita Creek basin in southern California using 3 precipitation stations separately and together, D. R. Dawdy and J. M. Bergmann (r0296) concluded that, for this site, peak-flow estimates simulated from precipitation records will have a standard error of estimate larger than 20 percent unless more than one precipitation gage record is used. They attributed at least this much error to variation in the areal distribution of precipitation over the basin during any one storm, and believe that the results are representative enough to indicate that the limiting factor for accuracy in most rainfall-runoff simulation studies will be the areal sampling error of rainfall measurement.

To help solve the problem of synthesizing long records of flood peaks at sites where only a few years of precipitation record are available, E. D. Cobb (r0296)
developed a procedure whereby long-term precipitation records from surrounding areas can be used by relating the resulting T-year floods for a site to a rainfall parameter and using this relation to select the applicable T-year flood. Although tested for only two stream sites in Alabama, the good correlation indicates that this or a similar relation could be similarly used in other areas.

Using drainage-area size as the only independent variable, E. E. Gann (1929) defined regional relations for flood-height frequency in the plains area in northwestern Missouri from which, for recurrence intervals of from 1.2 to 50 years, flood-heights above median stage (stage at the 50-percent duration discharge) can be estimated for ungaged streams with drainage areas greater than 50 sq mi. Standard errors of estimated flood heights range from 21 percent for the 50- and 25-year floods to 35 percent for the 1.2-year flood.

By theoretical analysis of randomly spaced events of random magnitude, W. H. Kirby (1950) showed that the occurrence of floods on small streams in humid regions can be adequately described by the Poisson process at flood levels higher than those that have an average recurrence of five times a year. His results confirm previous empirical observations of the applicability of the Poisson law to partial-duration series of flood peaks and have application to the problem of determining the probability of multiple exceedances in a given design period.

**Streamflow simulation**

By using a greatly simplified empirical method, D. O. Moore (1960) successfully synthesized daily discharge hydrographs from precipitation for several sites where at least 5 years of streamflow record were available and found good comparison between monthly mean flow from the observed and computed hydrographs. The method, which provides for separate development of the base flow and storm runoff components of the hydrograph, has primary usefulness in extending records of streamflow where longer records of precipitation are available. For the Hillsborough River basin in west-central Florida, however, J. A. Mann reported that a mathematical model of the method is being used to predict flood hydrographs from current precipitation records.

**Storage requirements and losses**

Full use of the amount of water available in a stream requires that runoff during periods of high flow be retained for use during periods of low flow. Research continues on procedures for determining the amount of storage required to provide selected draft rates and on how storage reservoirs affect the amount of water available for man's use.

M. E. Jennings found that storage-draft frequency relations for constant draft rates computed from synthesized sequences of monthly streamflow generated by a Markovian generating model check those obtained by combining carryover storage requirements obtained from a Markov-chain storage model (sometimes referred to as probability routing) and within-year storage requirements by the method now used. The advantage of using the synthesized sequences lies in the fact that the effect of variable draft rates and of serially correlated inflow can be evaluated.

If the volume of water lost from channel's downstream from flood-retarding structures in northeastern Texas is assumed to be virtually the same as before the structures were built, C. R. Gilbert and S. P. Sauer conclude that 102 structures, which will control approximately 25 percent of the 1,660-sq-mi drainage area above the Garza-Little Elm reservoir or Trinity River north of Dallas, would initially deplete the yield from the reservoir by about 10 percent. In the course of time, however, after the sediment pools at the retarding structures are substantially filled with sediment, the yield would probably return to normal.

**Volume of base flow**

Following up observations by earlier workers that drainage density is related to terrain permeability and to the base flow of streams, F. W. Trainer (p. C177–C183) used drainage density as an indicator of base flow in the Piedmont and Blue Ridge physiographic provinces in the Potomac River basin. For the 10 streams studied (see p. D22–D227 for related study on one stream), he found that the volume of base flow per square mile could be related to drainage density with a standard error of estimate of about 40 percent and that the use of the relation gave up to three-fold differences in estimated base flow from ungauged areas. His study suggests that drainage density may be useful in hydrogeologic mapping and in planning streamflow measurement for the study of base flow.

**Low-flow characteristics**

Steamflow to be expected during drought periods represents the amount of water available for man's use under natural conditions and thus defines the need for regulation. Research continues on procedures for developing low-flow frequency curves and on the significance of the information obtained from them.

For streams in Illinois, W. D. Mitchell and O. G. Lara found that low-flow frequency curves can be estimated from relationships based on the flow-duration
curve for a gaging station or for an ungaged site provided some low-flow information is available at the site. For steep duration curves they found that the corresponding frequency curves are steep and tend to be concave downward, whereas for flat duration curves the low-flow frequency curves for selected numbers of consecutive days are closely spaced and are concave upward.

In a study of the low-flow characteristics of streams in Washington, F. T. Hidaka and E. G. Nassar found that the median annual 7-day low flow at 87 stream gaging stations ranged from 0.06 cfs per sq mi to 6.07 cfs per sq mi, a 100-fold variation in this index of low-flow yield. The largest value of the index is for a stream that drains 12 sq mi of extensive swamps at fairly high altitudes in an area of southwestern Washington that receives large amounts of snow and rain. Other high values of the index are for streams that originate in icefields or glaciers, and the lowest indices are for low-lying streams in the Chehalis River basin in southwestern Washington.

John Skelton found that for streams in Missouri the 7-day low flow during the June to August growing season each year averages more than twice as large as the annual 7-day low flow during climatic years starting April 1. The average ratio of seasonal low to annual low ranges from 1.6 in the plateau region to 3.3 in the plains region and is of particular significance in the allocation of water rights for irrigation of row crops and summer pasture.

By inspecting an average of 9 years of streamflow recorder chart at 11 gaging stations in the Piedmont area of northern Georgia, W. H. Norris found that 13 percent of the days showed significant diurnal fluctuation. The drainage area of the stations ranged from 0.31 to 134 sq mi with a median of 17 sq mi. For the 1962 water year, the smallest stream studied shows fluctuations greater than 10 percent on about 33 percent of the days. Such fluctuations become troublesome when low-flow measurements at partial-record sites are being related to the flow at a stream-gaging station.

Accuracy requirements

Design of a program for obtaining and analyzing surface-water information is based on the premise that with more data the saving in the design of a water controlling structure would more than offset the cost of the additional data. Research has been started on procedures for determining at what point in time this premise ceases to hold and for setting accuracy goals.

Using a scheme he devised for determining how long to operate a stream-gaging station, M. E. Moss found that for a conservation-reservoir design on Arroyo Seco near Soledad in California the optimum length of streamflow record varies from 9 to 56 years, depending on the length of time that would elapse between the beginning of the record and the construction of the reservoir. The monetary benefits to be derived from the project are such that the project cannot afford to be delayed beyond 9 years solely for improving the accuracy of the streamflow record, but if the project is delayed for reasons other than data collection the accuracy given by the longer record could be justified.

C. H. Hardison (p. D210-D214) proposed that accuracy goals for streamflow characteristics, such as the 50-year flood, be equivalent to the accuracy with which the characteristic could be estimated from an observed record of some stipulated length. He used standard statistical methods to relate the accuracy of a T-year event based on N years of record to the variability of the annual flows and prepared curves and tables to aid in setting such goals.

Note.—For discussion of surface-water hydrology in which computer applications were used, see section entitled “Computer applications—surface water,” page A155.

**CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER**

**Temperature of streams**

In a study of water temperatures at sites on seven major streams in Texas, Jack Rawson found that air temperature is a reasonable index of stream temperature. The mean monthly water temperatures, as computed from daily observations, seldom differed from corresponding air temperatures at nearby U.S. Weather Bureau stations by more than 2°C. Moreover, the study showed that the temperature taken at any point in flowing water at most of the sites was closely representative of the average temperature in the stream cross section.

M. R. Collings and G. T. Higgins fitted the harmonic curve to 318 spot-temperature measuring sites and 44 sites with thermograph records. A comparison of amplitude, phase coefficient, and median annual temperatures between spot and recorded temperature for the 44 stations was made. The results indicated that the average difference of median annual temperatures is 0.3°C with 95 percent of the population being less than 0.6°C. The average difference in amplitudes is 0.3°C with 95 percent of the population being less than 0.6°C. The average difference in phase coefficients is 0.06 radians (about 31/2 days) with 95 percent of the population being less than 0.14 radians.
Water quality of streams and ground water

Differences in water temperature, chemical properties, and biological activity between night and day were studied at low flow on the Mattsole River, Humboldt County, Calif., by V. C. Kennedy and K. V. Slack. During low flow (about 40 cfs) the effects of biological and solar controls on water quality are especially evident. Observed ranges of environmental properties during the study period (September 30 to October 3) were as follows, day values being listed first: Water temperature, 19.7 to 14.4°C; light, 82,000 to 0 lux; dissolved oxygen, 11.5 to 8.2 mg/l; oxygen saturation, 124 to 82 percent; pH, 8.3 to 7.2; specific conductance, 280 to 266 μhmhos/sq cm. Moreover, the following changes were noted in evening water samples as compared to early morning samples: Calcium, −3.5 percent; magnesium, −3 percent; strontium, −6 percent; potassium, −2 percent; silica, +2 percent; bicarbonate, −5.5 percent. Because sodium remained virtually constant, the increase in silica in the evening was not due to concentration of the stream water due to evaporation. It may have resulted from uptake by diatoms to support cell division. Photosynthesis by streambed algae and respiration by the entire aquatic community controlled the dissolved oxygen and pH. Calcium, magnesium, strontium, and bicarbonate were removed in part by precipitation of carbonate, at least partly as the direct result of photosynthesis. The nocturnal increase in downstream drift of bottom-living invertebrates was confirmed by netting. Large amounts of a colonial blue-green alga (Nostoc) occurred in drift samples. A temporary increase in the drift rate of Nostoc during one afternoon was associated with wind-generated waves which dislodged masses of stranded algae from riffles and banks.

M. I. Kaufman reported that synthesis of available chemical data, including regional, time, and flow variations, emphasizes the close interrelations between the water-quality parameters of Florida streams and such environmental controls as surficial geology and cultural influences. Statewide regional distribution and seasonal variation patterns of nutrients (nitrate and phosphate), color, pH, dissolved solids, chemical type, hardness, and iron have been established.

Florida water is rather high in nutrients, and orthophosphate distributions can be correlated with industrial discharges, municipal discharges, agricultural drainage, and natural drainage from phosphate terranes. Linear relations exist between discharge and load.

Streams in Florida are very highly colored, and regional differences, environmental controls, and chemical associations have been established. Color is due to both natural decomposition of organic material and to cultural influences. Maximum color predominates during July to October.

N. F. Leibbrand reported that calcium, magnesium, and bicarbonate ions predominate in stream water in the State of Washington. Water containing 50 to 65 percent of these constituents is found in certain streams heading in the Willapa Hills. Water containing 65 to 85 percent is the most common type of water in the State. This type of water is found in most streams heading in the western slopes of the Olympic Mountains, the western and eastern slopes of the Cascade Mountains, and the streams in the southeastern part of the State.

Water in which calcium, magnesium, and bicarbonate ions constitute more than 85 percent of the total dissolved ions is found in a few streams heading on the eastern slopes of the Olympic Mountains, in a few streams heading on the eastern slopes of the Cascades in the northern part of the State, such as the Methow River, and in most of the streams in the northeast corner of the State, in the Selkirk Mountains, and further to the west in the Okanogan Highlands.

A study in the Medford, Oreg., area has shown that ground water of poor chemical quality is causing problems for many homeowners in the suburbs and rural sections. Concentrations of up to 11 mg/l of fluoride and 30 mg/l of boron have been found in some of the water yielded by Eocene and older formations according to J. H. Robison. Much of the affected water is of the sodium bicarbonate type.

Ground water and surface water in Santa Clara County, Calif., are being analyzed for 17 minor elements in an attempt to find a means of tracing the movement of water recharged to the underground reservoir, and to determine the distribution of the water containing these elements. R. C. Averett reported that the data collected to date are inconclusive. The analyses revealed a wide range in concentration in both ground water and surface water for the elements Al, Cu, Fe, Mn, Mo, Ni, Pb, Ti, V, and Zn. The elements Be, Bi, Ga, and Ge have not been detected in any of the samples. The concentration of the elements Cd, Cr, and Co varies considerably from site to site in the surface water, but is fairly uniform in the ground water.

Organic acids

R. L. Wershaw, P. J. Burcar, D. J. Pinckney, and S. J. Heller have obtained information on the chemical structure of humic and fulvic acids from zinc dust distillation and pyrolysis of these acids. Analysis of the decomposition products by thin-layer chromatography, gas chromatography, and mass spectrometry has
allowed some identification. In addition to providing structural data, these decomposition methods may be used to compare and characterize different humic and fulvic acids. They also have reported that the humic acids extracted from soil and water are generally made up of a number of fractions of different molecular weight, and have developed a two-step procedure (chromatography with ion-exchange cellulose followed by gel-permeation chromatography) to fractionate the humic acids.

R. L. Malcolm, E. A. Jenne, and P. W. McKinley have determined that both humic and fulvic acid fractions of soil and sediment organic matter form very stable complexes and perhaps chelates with Fe$^{3+}$ and Co$^{2+}$. The conditional stability constants ($\log K$ values) for these complexes were determined at a constant ionic strength of 1.0 in KCl by the resin-exchange method of Schubert using radioisotopic techniques. The conditional stability constants were 4.0 (pH 4.5) and 6.6 (pH 6.0) for fulvic acid-Co$^{2+}$ complexes, 6.0 (pH 4.5) and 8.3 (pH 6.0) for humic acid-Co$^{2+}$ complexes, 5.4 (pH 4.5) and 5.6 (pH 6.0) for fulvic acid-Fe$^{3+}$ complexes, and 6.6 (pH 6.0) for humic acid-Fe$^{3+}$ complexes. Thus, fulvic acid is an important scavenger of these ions in the natural environment and is important in the physicochemical transformations, transport, and distribution of these ions.

Surface sorption of organic solutes

As a method of elucidating sorption reactions, surface energy profiles were taken on mineral surfaces by M. C. Goldberg, F. H. Ono, and E. R. Weiner. The sensing element was gaseous ozone where the rate of ozone decomposition on a surface is indicative of the surface energy profile. Surface examination of silica spheres indicated that ozone decomposition occurred as a function of surface coating. When the surface was stripped of its coating there was rapid catalytic decomposition of ozone to oxygen. After gamma irradiation of up to 2 megarads the surface catalytic properties towards ozone were only slightly enhanced.

**RELATION BETWEEN SURFACE WATER AND GROUND WATER**

Geologic setting modifies low flow of streams

Analysis of low flows in the Susquehanna River basin in New York State shows that water loss to alluvial fans may substantially modify the flow characteristics of the stream. R. D. MacNish, A. D. Randall, and H. F. H. Ku found that flows of very small drainage areas measured in reaches lined with till or bedrock have high station-to-station correlation. In contrast, flow of these same streams measured on the alluvial fans shows almost no correlation with flows of upstream bedrock reaches or with nearby streams.

A preliminary appraisal of the water resources of a 28-county area in northwestern Missouri reveals that some streams have anomalous low-flow characteristics. E. E. Gann reported that these anomalies may be due to a hydraulic connection between the surface streams and buried glacial channels, which have been defined by test drilling. Water from some streams may move through the buried channels into an adjacent basin or basins. Some of these buried channels contain more than 100 feet of clean sand and are believed capable of yields sufficient for municipal, industrial, and irrigation supplies.

**Relation of floodwater from Hurricane Beulah to ground water**

Study of the relationship of impounded floodwater from Hurricane Beulah (September, 1967) to the shallow ground-water supply in South Texas reveals steadily declining stages in both surface and ground water, according to E. T. Baker, Jr. Since observation at three test sites began in spring 1968, the stage of the impounded flood water has declined as much as 3 feet, while the water table has declined as much as 5 feet. At two of the three sites under observation, the impounded floodwater is recharging the ground-water supply, but at the third site the shallow ground water is discharging into the lake. The study also reveals that, on the average, the total mineralization of the impounded water at the three sites has doubled, while that of the shallow ground water has more than tripled since spring 1968.

**Streamflow augmented by addition of ground water**

In a streamflow-augmentation study being conducted by R. P. Novitzki on a reach of the Little Plover River in Portage County, Wis., the response of water levels to an increase in stream stage was noted while water was pumped directly into the stream. Where water-table gradients toward the stream were steep, the aquifer and stream responded as a unit, with water levels exhibiting increases comparable to those in the stream. However, in one reach of the stream where water-level gradients were relatively flat, the increase in stream stage created a gradient away from the stream, with a resultant loss of streamflow to the aquifer. Eventually, water levels in the aquifer did rise, but the increases were not sufficient to reestablish a gradient toward the stream.

Ground-water development affects streamflow

A study of the effects of ground-water development on streamflow was made by E. P. Weeks and H. G.
Strangland in the central sand-plain area of Wisconsin where about 20,000 acre-ft of ground water was pumped in 1967 to irrigate 33,000 acres. In headwater areas, August streamflow is depleted about 30 percent. During severe drought the August flow might be reduced 70 to 90 percent by present development. Present ground-water use causes seasonal declines of about 0.5 foot in the regional water table and long-term declines of about 2 to 3 feet. Expanded ground-water development could lead to serious depletion of summer low flow of streams, but water levels would not be seriously affected.

**Reservoirs depleted by seepage**

Periodic severe water shortages at the city of Williams, Ariz., are the result of large seepage losses from the two largest reservoirs in the system. B. W. Thomsen reports that average monthly seepage rates are as much as 0.21 ft per day at Kaibab Reservoir and 0.14 ft per day at Dogtown Reservoir. The evaporation loss is about 4 ft per yr, and the seepage loss about 40 feet. Over half the inflow to the reservoirs is lost to seepage.

**Water-level response to imported water**

During the period 1958–63, application of imported water for irrigation in the Quincy Basin of central Washington caused water levels to rise over 30 ft per yr in basalt aquifers and about 3 ft per yr in the unconsolidated sedimentary material overlying the basalt. For the period 1963–68, H. H. Tanaka reports that March 1968 water-level measurements indicate that the average rate of water-level rise has decreased to less than 0.5 ft per yr and that recharge and discharge conditions are near equilibrium in this basin.

**Bank storage related to reservoir operation**

In a comprehensive study of the hydrology of Hungry Horse Reservoir, Mont., W. D. Simons and M. I. Rorabaugh show that there is about 200,000 acre-ft of active ground-water storage in the alluvium adjacent to the reservoir. The time response of this storage to changes in reservoir level was evaluated by a water budget and by a mathematical model. Reliability of results for the budget method is limited because of error accumulation, and for the model, by uncertainties in selecting hydrologic constants. However, optimization using both methods yields a usable solution. In addition to proving the existence of usable ground-water storage, which is of considerable economic value, the model provides the Bonneville Power Administration a tool for predicting the time availability of this water in management of the power resources in the Columbia River system.

**SOIL MOISTURE**

Advances have been made regarding the estimation of runoff and evaporation from, and moisture migration through, soils. Observations have also been made pertaining to factors that influence infiltration of water into the soil and its subsequent migration through the soil as either liquid or vapor.

**Need for estimating runoff and sediment yields from watersheds**

There is an urgent need for rapid, inexpensive, but reliable methods for estimating runoff and sediment yields from watersheds. Results of vegetation measurements on watersheds near Grand Junction, Colo., by F. A. Branson, J. R. Owen, and L. M. Shown, and measurements of the quantities of rainfall, runoff, and sediment yield by G. C. Lusby showed that statistically reliable relationships exist between the proportion of vegetative cover to bare soil and the amount of runoff from a watershed. The degree of correlation for data obtained from 17 watersheds over a period of 14 years was not improved when adjustments were made for slope or basin size. There was a very poor degree of correlation between the proportion of bare ground and the amount of sediment obtained from a given watershed. The area in which these relationships were measured receives an average of 8.3 inches of precipitation annually. Measurements of the proportions of bare ground and runoff obtained from other areas receiving higher average amounts of precipitation were also compared graphically. It has been concluded that this relationship must be determined for each climatic region, because the slope of the line changes as the amount of average precipitation increases.

**New method for estimating steady-state evaporation from playas**

C. D. Ripple, Jacob Rubin, and T. E. A. van Hylckama designed a new and simple graphical method for estimating steady-state evaporation from playas devoid of vegetation. The method involves computations based on readily obtainable soil-water parameter and meteorological information. The method was studied using data from U.S. Geological Survey water-table evapotranspirometers at Buckeye, Ariz.

**New technique for determining water diffusivity**

A new technique for determining water diffusivity in unsaturated soils was developed by Jacob Rubin and V. W. Adams. Their technique is based on measuring transient infiltration rates into soils, and involves computer solution of the unsaturated flow equation. In contrast to related transient state methods used until
now, the new technique does not call for determining the distribution of soil-moisture content during infiltration. Hence, it might be particularly useful under field conditions.

**Runoff and sediment in grazed and ungrazed watersheds**

G. C. Lusby determined that experimental watersheds at Badger Wash in western Colorado, after 13 years of grazing exclusion, yielded only about 75 percent of the runoff and 65 percent of the sediment yielded by otherwise similar but grazed watersheds. The difference between grazed and ungrazed basins was greatest during the third year of measurements.

Badger Wash is a tributary of the Colorado River and is in an area of often eroded marine shale classified as salt-desert shrub-type rangeland. This type of land contributes a large amount of sediment per unit of runoff to the river. Some improvement in plant cover has been measured, but it is believed that the reduction in runoff and sediment observed soon after grazing was excluded is due mostly to an increase in roughness observed at the soil surface that could decrease runoff and improve infiltration into the soil.

**Influence of different soil strata on infiltration from ponds**

Observations regarding the influence of different strata of soil on the rate of infiltration into the soil from artificial ponds were made by R. C. Prill. This study was conducted in southwest Kansas on a soil derived from loess. He found that rates of infiltration at the surface of the soil varied as water penetrated different strata of soil. Measurements of moisture content, made with a neutron moisture meter, indicated that moisture temporarily accumulated above restricting strata of soil, but that these accumulations dissipate soon after infiltration of water from the surface stops.

Water from the ponds at the surface caused the temporary accumulation of a mound of water several feet high above the water table. The specific conductance of the water in the mound was greater than the specific conductance of the water applied at the surface of the soil. This was attributed to the fact that salts were being leached from the soil down to the water table.

**Differences in soil-moisture utilization by various riparian trees**

Results obtained by I. S. McQueen and R. F. Miller in a study of moisture relationships on the flood plain of the Gila and San Carlos Rivers in Arizona indicate that there is a difference in soil-moisture utilization by different species of riparian vegetation. Moisture in the soil under saltcedar and willow trees is maintained in a near-equilibrium stress condition above a water table that is accessible to the root systems. Moisture in the soil under cottonwood and mesquite trees, however, is depleted, and the resulting stresses indicate utilization of moisture from the capillary fringe.

The persistent equilibrium stress condition measured under saltcedar and willow trees and the fact in one site the soil moisture increased during the season of maximum moisture use indicate that the roots systems of these trees may be distributing water from the water table to the soil to replenish water utilized by other shallow-rooted plants.

**EVAPOTRANSPIRATION**

Evapotranspiration is the sum of transpiration of water by plants and evaporation of water from the soil, water, snow, plants, and artificial surfaces. Evapotranspiration accounts for nearly 75 percent of the 30-inch average United States precipitation, for nearly all the precipitation in the arid regions, and approximately one-third of the precipitation in the more humid regions. The quantity and rate of evapotranspiration in largely determined by the availability of water, available energy, and the transport of water vapor from the evaporating surfaces.

The rate and quantity of evapotranspiration is important in water-resource planning, which includes prediction of water supplies available for agriculture and municipal usage, estimation of drought incidence, and the designing of storage reservoirs and conveyance systems. Investigations of evapotranspiration by the U.S. Geological Survey include studies of evaporation from lakes and reservoirs, evapotranspiration from vegetated land surfaces, and consumptive use of water by phreatophytes.

**Evapotranspiration by phreatophytes**

Depletion of soil moisture by tamarisk, rabbitbrush, and greasewood to depths of 5 feet below land surface with a water table at 7 feet was studied by M. L. Screy and E. P. Weeks by obtaining soil samples with a split-tube sampler and by sampling in the sides of pits. In coarse sandy soils adjacent to tamarisk stands, soil moisture was depleted from 5 percent by volume in winter to 2 percent by volume in summer. The root systems extended to the capillary fringe, suggesting that phreatophytes use both ground water and soil moisture when it is available and depend mainly on ground water when the soil moisture has been considerably depleted.

In the fall of 1967 and spring of 1968, T. E. A. van Hylckama made studies of the root systems that grew inside and outside of plastic-lined evapotranspiration chambers constructed in 1950 for a part of a phreato-
phyto study near Buckeye, Ariz., and reports that the plastic lining was not damaged during these years of burial. However, below the level at which the ground water was maintained, the outside of the plastic was covered by a dense network of small roots. It seems that even though the soil outside the evapotranspirometer is extremely dry, the temperature difference due to the cool water introduced into the evapotranspirometer is sufficient to induce condensation of water vapor in the soil outside the cool plastic. This concentration of moisture apparently accounts for the vigorous growth of saltcedar (Tamarix pentandra) bordering the evapotranspirometers.

Water use by arrowweed (Pluchea sericea) grown in plastic-lined lysimeter tanks was studied by O. M. Grosz near Imperial Camp, Calif. He reported that the average annual water use by 2-year-old stands of arrowweed growing in six of the lysimeter tanks was 333 cm with the ground-water table at 113 cm below the soil surface. In comparison, the average annual water use by 6-year old arrowweed growing in three of the lysimeter tanks was 193 cm with the ground-water table 122 cm below the soil surface. The difference in average annual water use is due to more growth and vigor of the 2-year-old plants as compared to the plants of the more mature stands of arrowweed.

Grosz made studies of water use by greasewood and rabbitbrush grown in plastic-lined lysimeter tanks near Winnemucca, Nev. He reported that the average seasonal water use by mature stands of greasewood was 38.5 cm with the water table 25 cm below the soil surface, and the average seasonal water use by rabbitbrush was 42.4 cm with the water table 19 cm below the soil surface. Of the total seasonal water use by greasewood and rabbitbrush, an average of 79 and 83 percent, respectively, was draft on ground water.

Evaporation from lakes and reservoirs

J. F. Turner, Jr., studied the influence of thermal loading on evaporation of water from Roxboro Lake, a 3,750-acre cooling reservoir for a 385-Mw steam-electric generating plant in north central North Carolina. Preliminary analysis of data indicates that thermal loading increased the annual evaporation loss by approximately 15 percent from June 1967 through May 1968. When the evaporation loss due to thermal loading is averaged over the area where it occurred (the artificially heated area), the increase amounted to approximately 67 percent of the total evaporation loss from the same area.

The mass-transfer coefficient, \( N \), used by G. E. Harbeck, Jr.\(^{70} \) in the evaporation equation \( E = N \Delta \theta \), was determined in a study by F. N. Lee for a small pond (approximately 2.5 acres) near Baton Rouge, La. Regression analysis of the data collected over a 5-year period (1962–67) resulted in a value for \( N \) of 0.00041 with the evaporation expressed in feet per day. This value compares reasonably well with coefficients computed for ponds of similar size and like climatic surroundings, but it is higher than the values expected in more arid regions.

A base loss of 0.0048 fpd (net effect of seepage, outseepage, and transpiration) was computed for the pond. Total losses from the pond (other than direct outflow) were defined by the equation

\[
L = 0.00041 \Delta \theta + 0.0048 + Y,
\]

where \( Y \) is the rate of seepage, outseepage, and transpiration, which varies with the different seasons of the year.

J. E. Heisel made intensive studies of radiation, temperature, humidity, and evaporation from Lake Greenwood in Martin County, Ind. Preliminary analysis of the data resulted in a mass-transfer coefficient for Lake Greenwood of 0.0066 with the evaporation expressed in centimeters per day. This compares favorably with the coefficient of 0.0056 determined for Morse Reservoir, 80 miles to the north.

Heisel's water-temperature studies showed that the water temperature during 1966 ranged from 6.5°C on March 27 to 23.4°C on July 7, whereas during 1968 the water temperature ranged from 8.9°C on March 29 to 24.8°C on August 25.

Energy-budget and mass-transfer techniques were used by J. S. Meyers during 1968 for estimating evaporation from reservoirs in various climatic zones and altitudes. The results of data collected from Elevenmile Canyon Reservoir (8,500 feet altitude) in central Colorado and from Falcon (300 feet altitude) and Amistad (1,200 feet altitude) Reservoirs in Texas indicate the relationships are better defined for warmer and drier southern sites at moderate altitudes than for cooler and more humid locations at higher altitudes.

**LIMNOLOGY**

**Effects of air injection on Lake Cachuma, Calif.**

Lake Cachuma, an impoundment on the Santa Ynez River in Santa Barbara, Calif., was studied before and during artificial circulation. Near-bottom injection of compressed air at two locations on the 3,000-acre impoundment reduced the thermal stratification,
reduced the size of the zone having less than 2.5 mg/l of dissolved oxygen, raised the bottom water temperatures, and apparently lowered the surface water temperature, according to M. W. Busby. Near-surface values of nitrate, phosphate, and silica were significantly lower than corresponding values below 10 m. This observation suggests that uptake of nutrients by phytoplankton in the photosynthetic zone was more rapid than nutrient replenishment by a combination of induced circulation and natural regeneration of nutrients.

**Phytoplankton cycles in Pretty Lake, Ind.**

Studies of phytoplankton dynamics through a second annual cycle in Pretty Lake, LaGrange County, Ind., by R. G. Lipscomb, continued to show large seasonal differences in algal populations. Diatoms again were dominant in the late fall and beneath the ice in the winter. Green algae were predominant in the late spring and most of the summer, and blue-green algae again were dominant in the late summer and the fall. Although the pattern of change for the major groups of algae was similar in both years, some differences were noted in the species that were present and in the abundance of predominant algae.

**Unusual temperature inversions observed in Salton Sea, Calif.**

During an evaporation study of the Salton Sea, Calif., which began on July 14, 1967, and ended on January 3, 1969, observations by A. M. Sturrock, Jr., and H. A. Moore of temperature with depth at 20 selected stations showed unusual temperature inversions occurring in the sea on October 23, 1968, and January 3, 1969. The location of the first inversion was approximately 2 miles from the east shore and near the center of the north-south axis. At this location, the lowest temperature in the sea was observed to be 6 feet below the surface. The distribution of temperature with depth showed the surface to be 23.5°C, the 6-foot depth to be 22.0°C, and the bottom (34 feet) to be 22.5°C.

The location of the second inversion was 1 mile from the north shore of the sea. At this location, the lowest temperature in the sea was observed to be 2 feet below the surface. The distribution of temperature with depth showed the surface to be 11.3°C, the 2-foot depth to be 11.2°C, and the bottom (30 feet) to be 12.6°C.

The unusual inversions were observed only on the given dates, and all other observations of temperature, which were taken at monthly intervals, indicated the lowest temperature in the sea to be at or near the bottom. Both inversions were observed during periods of low wind speed. Unfortunately, the observers were not prepared to sample the water at the time of observation, so that the cause and significance of the unusual temperature distributions are not known.

**Chemical changes in Great Salt Lake, Utah**

After completion of a semipermeable rockfill causeway across Great Salt Lake in 1959, the hydrology of the lake was altered. Before construction of the causeway, circulation of brine in the lake was unrestricted. Now 95 percent of the inflow to the lake is south of the causeway. Flow to the northern part is restricted to movement through the fill material and through two small culverts in the fill. Because of the retarding effect of the causeway and the change in inflow regime, brine in the north arm has become concentrated and that in the south arm has become diluted. Although the causeway divides the lake into two separate sections with complex inflow-outflow patterns, these two sections still react hydraulically in a manner similar to the original undivided closed lake, each establishing its own equilibrium between inflow and outflow. R. J. Madison reported that precipitation or solution of a salt crust in the north arm maintains the brine at about the saturation concentration of sodium chloride. By contrast, the concentration of the brine in the south arm varies with lake level (volume).

**Vegetative changes in Everglades National Park**

Changes in the size of the major vegetative communities in the Shark River Slough of Everglades National Park from 1940 to 1964 were determined by M. C. Kolipinski and A. L. Higer through photointerpretation. Their studies showed a decrease in acreage of aquatic sedges and grasses and an increase in woody vegetation. The probable reasons for the changes were shortened wet periods and increase in fires which resulted in a loss of peat soil.

**Vegetative changes in bottomland vegetation in Arizona**

Vegetation along the Gila River valley upstream from San Carlos Reservoir was mapped in 1914, 1943, and 1964. These maps of bottomland vegetation, plus old photographs and early written accounts, provided R. C. Culler and R. M. Turner with the basis for describing changes that began with a relatively complex and dynamic vegetation mosaic early in this century and ended with a relatively simple pattern today. The present stability is largely the result of a single aggressive, introduced species, saltcedar (Tamarix pentandra). Vegetation types dominated by cottonwood (Populus fremontii) and seepwillow (Baccharis glut-
nosa), in particular, are smaller in area. The change in plant species has undoubtedly been accompanied by faunal changes. There has also been a marked decrease in channel size and thus a lowered capacity to carry water during times of high flow. The rapid spread of saltcedar on the Gila and other rivers in western North America is a recent major disruption of the riparian habitat.

Seed production, dissemination, and seedling establishment of three arid botolmd phreatophyte species

To understand the encroachment of saltcedar onto bottomlands along many streams in the arid Southwest, R. M. Turner and D. K. Warren studied three phases of its life cycle related to seedling establishment: (1) quantity of viable seed produced by saltcedar, (2) season of seed production in saltcedar compared with the season in cottonwood and seepwillow, and (3) season of establishment of saltcedar seedlings.

During one season, approximately 100 saltcedar seeds per sq in. were caught in traps. These fell from late April until October with peak numbers in June or July and August. Seepwillow seed production is similar to that of saltcedar, whereas that of cottonwood lasted only mid-March to mid-April.

Saltcedar seedlings became established on the new beach of the receding San Carlos Reservoir soon after the seed fell. Seed establishment rate and timing were similar to those of dissemination. The greatest number of seedlings in any week were counted in early June when density amounted to 0.7 plants per sq in. A smaller peak occurred in August.

Prediction of flood frequency on the basis of botanical and geomorphic evidence

Long-lived trees of the California north coast were found by E. J. Helley to provide a means for predicting flood frequencies on the basis of the damage or death of these trees by floods or flood debris. Redwood (Sequoia sempervirens), Douglas-fir (Pseudostuga douglasii) and Port Orford cedar (Chamaecyparis lawsoniana) have been found to be particularly useful in extending our knowledge of the recurrence of devastating floods such as those of December 1964.

Tree rings and hydrologic conditions

The feasibility of identifying years of extreme hydrologic conditions in northern Virginia by the use of tree-ring size is under investigation. Current studies by R. L. Phipps have been aimed at delimiting extreme drought years. Shallow rooted trees, such as yellow poplar (Liriodendron tulipifera), growing in wet lowland habitats can be expected to produce large annual growth rings during most years. Pronounced growth response, expressed as a significantly small ring, occurs when drought conditions are extreme enough to lower the water table of the lowland below the tree root-zone. Preliminary investigations of the frequency of occurrence of such extreme drought conditions have been hampered by the fact that most secondary or tertiary forests of the study area lack trees old enough to indicate responses to more than one or two extreme droughts.

Diurnal and seasonal sap pressure of phreatophyte species

Negative sap pressures in the xylem of two phreatophyte species growing in the Gila River valley, Arizona, were measured at irregular intervals by R. M. Turner for a period of 1 year by means of the Schoander pressure apparatus. In general, values for saltcedar (Tamarix pentandra) were lowest where water tables were shallow and highest where water tables were deep. During the summer, values ranged from roughly 7 to 25 atm. These values increased from September to January when values of 70 to 94 atm were measured.

Values for mesquite (Prosopis juliflora) were lowest (10 to 20 atm) in March or April and increased to values of 33 to 40 atm in September and October.

Pressure changes were followed through one night in September. In both saltcedar and mesquite, low values of 7 to 13 atm were reached between sunset and midnight. These values were maintained until sunrise, when the pressure increased abruptly to values of 28 to 30 atm.

In all these tests, changes in pressure seem related to tree species, to meteorological conditions, and to water-table depth.

Time interval for establishment of tree seedlings at Mount Rainier, Wash.

Ages of young landsforms and deposits can be estimated by determining the age of the oldest tree on the deposit. A main source of error in estimating the age of a deposit from tree ages was found by R. S. Sigafoos and E. L. Hendricks (p.B89-B93) to be the interval between the stabilization of the deposit and the growth of tree seedlings. They found that this interval ranges from 1 to 35 years at different places at Mount Rainier, Wash., and the reasons probably lie in different combinations of seed supply, climate, and the existence of a suitable seedbed. Their study emphasized the need to determine the interval at each study area.
NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

Recording of data

The program of conversion from analog to digital recording is progressing smoothly. The Water Resources Division of the U.S. Geological Survey now has approximately 7,000 digital recorders in use. Although the majority of these are still used for recording only water stage, an increasing percentage are being used for water-quality monitoring and other hydrologic applications.

G. F. Smoot reported the development of a solid-state timer for programming the digital recorder. One hundred of these solid-state timers have been sent to the field for thorough testing and evaluation.

Measurement of discharge

A specially designed boat with accessory equipment is now being used to measure discharge of the Columbia River. N. A. Kallio described the special boat design as including an instrument well at midship and a jet system for maneuvering to maintain position without anchoring. Two Price current meters suspended through the well are automatically lowered to 0.2 and 0.8 of the depth of the water at the point of observation. Velocities are measured simultaneously at these depths and recorded electrically. Cross-section stationing is determined with a ship-to-shore tellurometer system. Any tendency for the boat to move while measuring is detected electrically, and the magnitude and direction of this movement is displayed on a panel of lights mounted in front of the boat operator.

Field tests show that discharge measurements from the boat are reliable. The cost of boat and equipment is considerably less than that of a cableway across the Columbia, and furthermore, the boat can be used for making measurements at many sites. A study evaluating an acoustic flowmeter (a device which measures the average velocity at the elevation of, and parallel to, a diagonal line across a stream channel) for use in measurement of the net fresh-water outflow from the central valley of California to the ocean was reported on by Winchell Smith. The conclusions, stemming from detailed study of the channel hydraulics of the Sacramento River near Pittsburg, Calif., are the meaningful discharge figures could be obtained if a reliable acoustic flowmeter were available and if techniques were devised for accurate in-place calibration of the measuring system.

Acoustic flowmeters are currently being developed by commercial firms, and a suitable device probably will be available soon. The impending availability of such a device lent impetus to the development by Winchell Smith of the current-meter discharge-measurement techniques needed for calibration. A suitable measuring system has been devised, and prototype hardware has been assembled and tested. Measurements are made from a boat using (1) a tellurometer and an optical tracking system for positioning the boat, (2) a fathometer for defining stream depth, (3) two current meters positioned relative to depth by proportionately coupled winches, and (4) a remote indicating compass mounted below one of the current meters to define the direction of the velocity vector. Data are recorded automatically as the boat traverses the measuring section. A complete traverse, defining velocities and depth in as many as 150 subsections, can be made on a wide stream (3,000 feet) in less than 15 minutes. This permits definition of flow at frequent intervals and provides data for the complex interpolation routines applied in the computer programs used for computation of discharge.

The two series of measurements made in the Sacramento River channel near Pittsburg, Calif., have demonstrated the capability of the system and provided data for development of the computer programs. The system, as designed, provides a means for accurate definition of discharge in large streams subject to tidal action, including those where reversals of flow occur with each tidal cycle.

Relative to the technique of determining discharge of large rivers by considering a dam, its gates, and its turbines as a streamflow-measurement structure, that can be calibrated, H. O. Wires reported that recently improved instrumentation is producing better records for analysis and is prompting more applications. Improved accuracy and ease of recording turbine flow is anticipated by the design of a servo differential pressure manometer for recording integrated values of scrollcase piezometer tap-pressure differences. A prototype now being tested at Markland Dam on the Ohio River shows much promise.

Measurement of velocity

G. F. Smoot reported that a new type of deflection vane has been designed which records on the analog digital recorder. Several of these units have recently been installed in the field, and thus far results appear to be excellent. In addition to the advantage of operating in conjunction with the analog digital recorder, the vane is small, and is easy to install and maintain.

The heated multiple-thermocouple probe with sensitivities below 0.1 fps was placed in open-channel flow conditions after successful flume tests, according to H. O. Wires. Because of the sensitivity and high rate of
response of the probe, making a visual reading is difficult because of the effect on the probe of natural turbulent fluctuations. Therefore electronic integrating circuitry is being designed to permit accurate visual or recorded readings for standard discharge rating techniques.

**Measurement of turbulence**

J. P. Bennett reported that a propeller-type flometer with a small, light propeller can be used to measure the turbulence characteristics of large-scale open-channel flows, if corrections are made for the frequency response and spatial averaging characteristics of the propeller.

**Borehole geophysics**

W. S. Keys reported that with the use of recently developed equipment, gamma-emitting isotopes can be identified in wells as much as 2,500 feet deep and as small as 2 inches in diameter. The downhole and surface equipment is readily adapted to any logger that uses single-conductor cable. This system has been used for the in-place identification of naturally occurring radioisotopes, radioisotopes disposed in liquid waste, and radioisotopes created by in-hole neutron activation. Activation was done with californium-252, which was used for the first time in well logging. It has a neutron emission rate 300 times that of any other available radionuclide. The following nuclear reactions were induced in a borehole, and the product nuclides were identified: $^{27}$Al($n,\gamma$)$^{28}$Al, $^{23}$Na($n,\gamma$)$^{24}$Na and $^{56}$Fe($n,p$)$^{56}$Mn or $^{56}$Mn($N,7$)$^{56}$Mn. Aluminum was activated and logged on a continuous basis, which provides a new means for distinguishing clay-rich sediments. Activation analysis of sodium may be useful in investigations of saline waters. The relative concentration of natural radioisotopes is more diagnostic for the identification of sediments and depositional environments than is gross gamma activity, and also may indicate the amount of leaching by ground water.

**Multiphase flow**

Recent work by E. P. Weeks and G. E. Ghering indicated that pressure changes in small-diameter piezometers open to air in the unsaturated zone of porous earth materials may be measured with aircraft altimeters or differential manometers filled with low-density oil. The measurements may be used with a method developed by R. W. Stallman for determining air permeability from an electric analog model of the attenuation and phase lag at depth of air-pressure changes resulting from atmospheric fluctuations.

A relationship exists between thermal conductivity and soil moisture, according to C. R. Daum. However, that relationship varies with different soils, and, at present, each soil must have its own calibration curve. A long time recording has been completed at four different depths to 25 cm in soils as a "backyard" project in Boulder, Colo. Soil samples were taken at the different depths, and calibration curves were constructed for soil moisture versus conductivity. Accordingly, hourly variations in soil moisture have been determined and plotted.

**Use of time-lapse photography in hydrology**

J. R. Beck reported that the processes of soil and beach erosion were captured on 16-mm color motion picture film by time-lapse photography. A camera installed in a small drainage basin near Palo Alto, Calif., is observing changes in channel morphology. The camera is triggered automatically by rainfall and light intensity. A 100-foot roll of film lasts between about 30 to 100 hours of recording; recording time varying with frame frequency, which is adjustable. A second camera installed at Bolinas, Calif., is viewing a narrow sand spit from atop a hill overlooking Bolinas Lagoon. Pictures are obtained during both high and low tide, and the camera is triggered automatically by time and light intensity. A magazine with 50 feet of film lasts nearly a month and is easily serviced. Both cameras make use of photocells and obtain their power from dry cells.

**Analysis of hydrologic data**

A preliminary study by J. W. Rabon indicated that the factors necessary for the solution of polynomials describing flow in tidal reaches may be taken directly from recorded and observed data. The study indicates that the flows of the St. Johns River at Jacksonville, Fla., may be determined within acceptable accuracy by solving a set of approximated polynomial equations of the parametric type where the parameter is time, written $y=f(t)$. The polynomial equations are approximated by taking advantage of recorded or observed critical points (when $f'(t)=0$) and other accurately defined points when both the time variable and the dependent variable $y$ are known, such as $(t_1, f(t_1))$. Methods presently being used for determining the flow volumes at the Jacksonville station give results of questionable accuracy and are tedious and time consuming to apply. Final results of this study will determine whether a velocity vane is necessary for improving the rating or whether the present equipment is sufficient to determine flows to desired or required accuracy. About 14 years of record have been collected at the site; if final results are successful, this invaluable record could be improved.
A similar study is being made to determine a satisfactory method of computing the flow of St. Johns River at Palatka, Fla., to the required accuracy. The knowledge of flow characteristics at this site will be the basis for defining a satisfactory rating or for moving to another test site.

**Geology as a parameter in estimating mean runoff**

Statistical multiple-correlation techniques were used by Elmer Butler to relate mean annual runoff to drainage area, mean annual precipitation, and to a weighted geologic index in a region in the Wasatch Range from Holmes Creek south to Emigration Creek east of Salt Lake City. The regression analysis indicated that for this area the use of a weighted geologic index as one of the independent parameters did not significantly improve the estimate of mean annual runoff.

**Computer applications—surface water**

A number of complex hydrodynamic phenomena, such as the wave-crest movement or traveltime of particles in transient open-channel flow, can be investigated by numerical experiments using an appropriate mathematical model. The results of numerical simulation can then be visually and effectively displayed by one or another form of new techniques in computer graphics, as for example, by a computer animated motion picture. Chintu Lai (r2179) performed a series of numerical experiments for tidal and flood flows, using mathematical models that simulate unsteady flows in rivers and estuaries. He found that intricate transient motions of water-surface movement, wave propagation, index-particle travel, and so forth, can be pictorially demonstrated for direct visual observation. From such graphical outputs, a large amount of valuable information, such as the traveltime of an index particle to a reservoir or to the ocean, the effect of particle injection at different locations or at different times, comparison of traveltimes of the particle and of the flood wave, travel distances of the particle in ebb and flood flows, the reciprocal motion of the particle and its net downstream movement in the estuary, and so forth, can be obtained both qualitatively and quantitatively.

**Computer applications—ground water**

The unsteady flow of ground water in an aquifer can be described by elliptic or parabolic partial differential equations. These equations can be approximated by finite equations. The solution of these finite difference equations for a nonhomogeneous anisotropic and leaky artesian aquifer having irregular boundaries, differing boundary conditions, and multiple variable-rate pumping (or recharge) wells has been accomplished. An efficient and well-known numerical technique for solving the equations in two-space dimensions with time is the alternating direction implicit technique. This technique is readily programmed for digital computers. Jacob Rubin has used this and other techniques to investigate the flow of water through unsaturated and saturated soils.

G. F. Pinder and J. D. Bredehoeft used similar numerical techniques to solve ground-water problems. Several comparisons of the numerical solutions versus analytical solutions for homogeneous isotropic aquifers of simple geometry were made. The numerical results show good agreement with the analytical solutions. As a further check the numerical results were compared to electric analog results for a nonhomogeneous aquifer having complicated and irregular boundaries. Both techniques provide results in good agreement.

In fiscal year 1969, the digital ground-water model was used to analyze a number of field problems in such widely scattered states as California, Colorado, New Jersey, New Mexico, South Dakota, and Washington. A problem involving 2,000 nodes and 250 time frames requires approximately 45 seconds of computer time on a CDC model 6600 computer or approximately 8 minutes on a IBM 360 model 65 computer. The finite-difference grid for a problem in the Permian reef complex in New Mexico and Texas is set up with a 1-mile node spacing on an 80 × 191 grid (approximately 15,000 nodes). The reef complex can be analyzed for 100 time frames in less than 5 minutes using a CDC 6600 computer.

These numerical techniques make it possible to rapidly analyse a ground-water flow system and to describe the dynamics of the physical system as the base from which to optimize the total water-resources system.

A computer program was written to yield histograms that show potential water-yielding ability of lithologic units in Oakland County, Mich., where ground-water reservoirs in glacial deposits are not easily delineated. Stratigraphic correlation of individual units over all but local areas is impossible in this area. Isopach and lithologic maps, based on drillers' logs and constructed for 50-foot vertical intervals, were prepared by F. R. Twenter and R. L. Knutilla to identify areas where the glacial deposits are composed of “aquiferlike” materials. To construct the maps, Twenter and Knutilla selected and coded a large number of drillers' logs for manipulation by methods of automatic data processing. A number was assigned to each of the major rock types as well as to those lithologic characteristics and minor rock constituents that modify the major rock types. For a given rock type, this number was a reflection of the percentage of aquifer-
like materials making up a particular rock unit and the unit's ability to yield water. For the modifying characteristic or constituent, the number reflected the modification made on the water-yielding ability of the rock. A computer program devised to evaluate the data yielded histograms showing the percentage of aquifer-like material in each 50-foot unit and, thus, the potential water-yielding ability of the unit. Map plots of these percentages, produced by computer, provided a first approximation of areal distribution of ground-water reservoirs.

**Computer applications—water management**

The techniques of operations research can be applied to problems of water-resources management. The U.S. Geological Survey has established a systems analysis laboratory, headed by N. C. Matalas, which is responsible for this effort.

As part of the Survey's systems investigations I. C. James II completed a study in which the operation of a reservoir-estuary system was simulated using the digital computer. The sensitivity of the system performance to four variables: (1) hydrologic inputs, (2) behavior models for the estuary, (3) waste loads, and (4) water quality objectives, was tested. The results suggest that the economic variable, in this case the waste-load projection, is the most important planning variable.

A computer simulation of the conjunctive use of both ground water and surface water in the Arkansas River valley of Colorado was completed by I. C. James II. The objective was to assess the ability of various water-management alterations to better match the distribution of supply with demand.

**Use of data banks**

J. M. McNellis, C. O. Morgan, and B. H. Lowell (r2573) used computer-produced tables, maps, and diagrams from coded data to facilitate further collection and interpretation of ground-water data and to solve various quality-of-water and hydrologic problems.

**ANALYTICAL METHODS**

**ANALYTICAL CHEMISTRY**

**Determination of palladium and platinum by atomic absorption**

Palladium and platinum are determined by atomic absorption after these elements are concentrated by fire assay into a gold bead, according to M. M. Schnepfe and F. S. Grimaldi (r2465). Approximately 0.1 ppm of each of these metals is determinable as a lower limit on a 20-g sample. Serious depressive interelement interferences in the atomic-absorption determination are removed by buffering the solutions with a mixture of cadmium and copper sulfates with cadmium and copper concentrations each at 0.5 percent. Substantial amounts of Ag, Al, Au, Bi, Ca, Co, Cr, Fe, Hg, K, La, Mg, Mn, Mo, Na, Ni, Pb, Te, Ti, V, Y, Zn, and platinum metals can be tolerated.

**Determination of rhodium by atomic absorption**

A method for determining small amounts of rhodium was developed by M. M. Schnepfe and F. S. Grimaldi. Rhodium along with palladium and platinum, is concentrated by either a tellurium precipitation or by fire assay. After solution of the tellurium precipitate or fire-assay gold bead, rhodium is determined directly by atomic absorption in a solution buffered with lanthanum sulfate. The buffer removes interference from other elements and at the same time increases the sensitivity of the rhodium determination. A sensitivity of 10 ppb is obtainable on a 20-g sample.

**Determination of micro amounts of cesium in geologic materials**

The cesium content of rocks can be determined either by X-ray fluorescence or atomic absorption in a method developed by Wayne Mountjoy and J. S. Wahlberg. Cesium is concentrated from a solution of the rock on an ion-exchange column of ammonium molybdophosphate. Cesium is then determined by X-ray fluorescence analysis of the ammonium molybdophosphate or by atomic-absorption analysis of a potassium hydroxide solution of the molybdophosphate. The sensitivity for both procedures is about 0.3 ppm on a 2-g sample.

**Powder density of rocks**

A simple sink-float procedure for determining the powder densities of most rocks was developed by Leonard Shapiro (B140-B142). Small samples are centrifuged in a sequence of heavy liquids selected to establish density within narrow limits. Observations on whether the sample floats or sinks in the liquids enable density to be determined within ±0.04 units. Approximately 0.1 g of sample is used.

**ACTIVATION ANALYSIS**

**Activation method for platinum and palladium**

J. J. Rowe, F. O. Simon and H. T. Millar, Jr., developed a method for determining platinum and palladium, using fire-assay preconcentration. Ten to twen-

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ty g of sample is processed by the fire-assay procedure. The resulting silver bead is then irradiated in a reactor. The platinum and palladium are each radiochemically separated in a pure state, beta counted, and decay curves are plotted to verify the purity of the final precipitates. The Pd^{109} formed from the Ag^{109}(n,p)Pd^{109} reaction of the 2-mg silver bead was found to be equivalent to 0.2 ppb Pd (on basis of a 20-g sample). The preliminary results for platinum and palladium in standard sample W-1 compare favorably with determinations by other methods.

**Activation method for gold in phosphatic materials**

An activation analysis method for determining gold in phosphatic materials was developed by J. J. Rowe. In usual activation procedures, direct irradiation of samples with thermal neutrons leads to high induced activity in samples containing phosphorus. By using only epithermal neutrons in the irradiation, the activation of phosphorus is reduced drastically without seriously affecting the activity of gold. It is thus possible to determine gold in apatite after a very short post-irradiation cooling period.

**Determination of germanium by activation analysis**

L. P. Greenland and J. E. McLane (p. C152-C154) developed a rapid method for determining germanium in silicates by neutron activation. Samples of 10 to 100 mg are irradiated for 10 minutes in a reactor. Germanium is purified radiochemically by extracting germanium tetrachloride into carbon tetrachloride from 9M hydrochloric acid solution and then is determined by beta counting the 82-minute Ge^{75}. The chemical yield of the procedure is determined by reirradiation. As little as 0.2 nanogram of Ge can be detected, and amounts exceeding 1 ng are being determined routinely.

**Pneumatic sample changer for scintillation detectors**

A pneumatic sample changer for well-type and flat scintillation detectors was developed by a team consisting of C. J. Massoni, R. V. Fones, J. F. Abell, J. J. Rowe and F. O. Simon. A "rabbit" containing the sample to be counted is dropped into a well (or on top of the detector if flat geometry is used) by a gate. The gate is so constructed that the sample to be counted is held while a 3-second blast of air ejects the previous sample. If the sample fails to eject, the system will shut down and a light will indicate the failure. No further changes will occur until the system is reset manually. The sample changer will increase counting capabilities by a factor of 3-4.

**OPTICAL SPECTROSCOPY**

**Computer completed analysis**

When chemical elements are determined in geologic materials by optical emission spectrochemical methods (1) a small amount of the sample is made to produce characteristic radiation, (2) the radiation is recorded as a spectrum on photographic plates, and (3) the analyst with tedious measurements and calculations determines composition of the sample from the spectrum. The possibility of employing a computer to aid this work is very attractive, not only because it might reduce the amount of labor, but also because it might minimize the subjective nature of the work and use more of the data available in each spectrum. The feasibility of automating the analysis beyond the point of photographing the spectrum has been demonstrated with a spectrum-reading and data-handling system developed by A. W. Helz, F. G. Walthall and Sol Berman.

In the system they developed, all the information from a photograph spectrum is transferred to magnetic tape by recording digitized microphotometric readings taken at equal increments of length along the spectrum. The computer is programmed to select pertinent spectral lines and background information from these data, to complete all calculations including plate calibration, conversion to intensities, background corrections, spectral interferences, element concentrations, and so forth, and to supply a printout of the report. The system is adaptable to any number of spectral lines or elements and, conversely, to the determination of wavelength of spectral lines. Special attention is given to the spectral-line finding program.

Sufficient resolution without a sacrifice of information is obtained from spectra (5 A/mm) when readings are taken every 5 μ along the length of the spectrum with a scanning aperture 10 μ wide. Wavelength accuracy is assured by the use of known spectral lines as internal fiducial lines.

**X-RAY FLUORESCENCE**

**Pressed powder pellets for X-ray fluorescence analysis**

The preparation of pressed powder pellets is a critical step in X-ray fluorescence analysis. A special die was designed by Brent Fabbii that produces extremely smooth and durable pellets. The sample is pressed with a backing and outer ring of cellulose. The outer ring minimizes deterioration of the edge that has limited the usable life of the pellet in the past. Repetitive preparations have shown reproducibility and homogeneity to be within normal counting statistics.
Soft X-ray spectrometer

The installation of a soft X-ray spectrometer in U.S. Geological Survey Laboratories has opened up new areas of research and has extended analytical capabilities. The instrument provides either electron or X-ray excitation with a choice of six targets for maximum efficiency. The elements from boron to fluorine are now detectable. J. R. Lindsay and H. J. Rose, Jr., have established detection limits of 100 ppm for Si, Al, Na, and F. Small energy shifts observed in the X-ray spectra of a variety of minerals are being correlated to oxidation state and chemical bonding.

Electron-probe study of band coloring in sphalerites

Band coloring in sphalerite normally varies from colorless to yellow to dark red brown, and has been attributed to variations in iron content. Attacking this problem with the electron probe supplies an analysis of individual “colloform” bands. In such a study of sphalerites from Pine Point, Northwest Territories, Canada, E. W. Roedder and E. J. Dwornik (r2442) found no correlation between iron content and color.

ANALYSIS OF WATER

Automated titrimetric analysis

Automated titrimetric analysis has been applied to the determination of alkalinity, chloride, and sulfate in fresh water by M. J. Fishman and R. F. Pascoe. The titrimer can be programed to carry out, automatically, any titration—acid-base, oxidation-reduction, precipitation—which gives a reproducible potentiometric end point. A photometric accessory unit can be programed to carry out most standard colorimetric titrations. Replicate analyses and comparison of results with those obtained by manual titrations show that the automated methods are accurate, reproducible, and provide a rapid means for the determination of these substances in water.

Pesticides

In a study of methods for removing extraneous materials from pesticide-containing extracts of soil and water, L. M. Law and D. F. Goerlitz devised microcolumn cleanup techniques that are both rapid and economical. Three absorbents—alumina, silica gel, and Florisil—were investigated. The microcolumns were found useful for separating a variety of pesticides, pesticide metabolites, and manufacturing precursors from coextractives. In addition, it was found that certain pesticides which are difficult to separate by usual gas chromatographic procedures could be separated using the microcleanup columns. The developed techniques have further application by providing cleaner extracts, thereby allowing the sensitivity of routine analysis to be increased severalfold.

D. F. Goerlitz and L. M. Law also evaluated several gas chromatographic detection systems for the determination of phosphorothioate pesticides in water and sediment. They found that, at least in its present stage of development, the flame-thermionic detector is unreliable for quantitative work, but may be useful for identifying specific phosphorus compounds. The response of the flame-thermionic detector during repetitive testing varied as much as 50 percent with an average error of 10 percent. As an alternative, the electron-capture detector proved to be usable for the determination of phosphorothioate compounds but has limited application because it is nonselective. Also, the electron-capture detector was often disabled or impaired by many of the polar solvents tested, thus placing serious limitations on sample-preparation techniques. Another system, the flame-photometric detector, was also evaluated. This detector responds quite specifically to either phosphorus or sulfur, and the mode of detection is selectable. The flame-photometric response is linear and is at least as precise as the sampling techniques applied. In addition, the flame-photometric detector is not sensitive to relatively large amounts of extraneous organic matter, and the response was not affected by the dilution solvents tested.

Humic and fulvic acids

R. L. Malcolm developed a procedure for obtaining relatively ash-free humic and fulvic acids from water and sediment. The procedure involves extraction in dilute base, centrifugation, pressure filtration, dialysis, resin exchange, and lyophilization. The properties of humic and fulvic acids vary with ionic saturation and amount of inorganic impurities (clay minerals, amorphous silica, aluminum, iron, and various metal ions). These impurities also interfere with elemental analysis, exchange phenomenon, infrared analysis, and with all phases of organic-matter research. Therefore, it is imperative to use relatively ash-free, hydrogen-saturated humic and fulvic acids in organic studies to establish the true nature and reactivity of natural organic substances in water and sediment.

Gold and silver

Studies by T. T. Chao, E. A. Jenne, and L. M. Heppington (r0287) showed that trace amounts of gold may be kept in solution without being adsorbed onto polyethylene-container walls by (1) acidification of a test solution to pH 1 with hydrochloric acid and addition of between 5 and 50 mg/l Br, (2) acidification with hydrochloric acid to 1N without bromine, and (3)
acidification with nitric acid to 2N and 3N. The pH 1 hydrochloric acid and 50 mg/l Br combination is also effective in desorbing gold from container walls.

The use of strong acids is the most effective means of retaining traces of silver in solution (Chao, Jenne, and Heppting, r0286). Lowering the pH of a test solution to 1 with either hydrochloric or nitric acid reduces silver adsorption onto polyethylene containers to approximately 1 percent for more than 30 days. The same treatment may remove silver from container walls in the course of a few days.

A method was developed by T. T. Chao whereby nanogram amounts of gold in water can be accurately determined. A water sample is first acidified with hydrochloric acid to pH 1, and then 50 mg/l Br is added to prevent gold adsorption onto container walls and to maintain optimum conditions for its recovery by an AG 1×8-in. resin column. The gold is eluted from the resin with an acetone-nitric acid-water mixture and determined by atomic absorption spectrophotometry after MIBK (methyl isobutyl ketone) extraction. Twenty to 50 ng/l Au can be accurately determined from 25 to 10 l of water, respectively.

E. A. Jenne, T. T. Chao, and L. M. Heppting (r2133) found that the slurry techniques using mercurous chloride for the recovery of trace amounts of gold from water to be unreliable. Instead, the use of a very thin mercurous chloride layer on a membrane filter results in quantitative recovery of gold. The presence of other metal ions does not interfere noticeably with the recovery of gold by this method.

A separate study by T. T. Chao, M. J. Fishman, and J. W. Ball resulted in the development of a new technique to determine trace amounts of silver in water. For silver concentrations within the range of 0.1 to 1 μg/l of water, preconcentration through an ion exchange resin column is required. The silver is then removed from the resin and measured by atomic absorption spectrophotometry after chelating the silver with APDC (ammonium pyrrolidine dithiocarbamate) and extracting the chelate with MIBK. Silver, at concentrations of 1 to 10 μg/l, can be determined by direct APDC–MIBK extraction without preconcentration.
GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Earthquakes triggered by fluid injection

J. H. Healy and C. B. Raleigh (U.S. Geological Survey) and W. W. Rubey and D. T. Griggs (University of California, Los Angeles) provided strong support for the proposal that a series of earthquakes which began near Denver, Colo., in 1962 were triggered by injection of fluid into basement rocks through a deep disposal well at the Rocky Mountain Arsenal (Healy and others, 1967). The suggested triggering mechanism is reduction of frictional resistance to fracturing through an increase in pore pressure, according to the Hubbert-Rubey theory. Withdrawal of substantial quantities of fluid, therefore, should reduce the size and number of earthquakes.

Tests of the feasibility of withdrawal of fluid from the Rocky Mountain Arsenal well were reported by D. B. Hoover and J. A. Dietrich (1968) for two major periods of pumping. No unusual seismic activity was noted during the pumping; however, a temporary increase in seismic activity occurred after both periods. Altogether, about 0.2 percent of the injected fluid was withdrawn.

Another instance of earthquakes probably triggered by fluid injection has been recognized near Rangely, Colo. The earthquakes there originate near the depth of a reservoir into which fluid is being injected for secondary recovery purposes, and the epicenters correlate with high fluid-pressure gradients.

Earthquakes triggered by an underground nuclear explosion

The seismic effects of a 1.1-megaton nuclear explosion detonated 1.4 km beneath Pahute Mesa at the Nevada Test Site were monitored by 27 seismograph stations. Analysis of the data by R. M. Hamilton and J. H. Healy reveals that the explosion triggered a sequence of earthquakes lasting several months in an elongate region extending about 13 km from about 3 km from ground zero. The aftershocks occurred from the surface to a depth of about 10 km, and the epicentral region migrated southward as the sequence progressed. The nature of faulting, as deduced from first-motion data, exhibited temporal variation from dip-slip movement in the early stages to strike-slip movement at the end. Evidence suggests that the explosion caused release of natural tectonic stress.

Microearthquake studies

A telemetered network of 32 short-period seismographs was maintained in central California during 1968. New networks were established in southern Nevada at the Nevada Test Site (7 stations) and in central Idaho at the Nuclear Reactor Testing Station (7 stations).

Approximately 300 small earthquakes originating in central California are recorded each month. Analysis by J. C. Roller, J. P. Eaton, and W. H. K. Lee (1968b) shows that the concentrations of foci are most dense (1) along the Sargent fault west of Gilroy, (2) along a line about 5 km east of the Calaveras fault between Hollister and Hayward, (3) along the San Andreas fault west of Hollister, and (4) along the San Andreas fault in the Parkfield-Cholame area. The foci were confined to depths less than 15 km.

Intensive studies of aftershocks of several moderately large California earthquakes have been made with temporary clusters of up to 20 self-contained portable seismograph stations. Calibration shots and special refraction profiles have been used to improve the precision of aftershock hypocenter determinations. Two sequences studied by J. P. Eaton point to contrasting styles of rupture along the San Andreas fault. One study of 600 aftershocks of the 1966 Parkfield-Cholame earthquake shows that they were concentrated in a long, extremely narrow, nearly vertical zone whose upper edge is coincident with the zone of surface fracturing and which extends to depths of 12 to 15 km. First-motion patterns of a large majority of these aftershocks are compatible with right-lateral strike-slip movement along the slip surface outlined by the aftershocks. In the other study, about 400 aftershocks of the 1967 Bear Valley earthquake were concentrated, within the rift zone, in a roughly equidimensional region that is about 3 km across and extends from the surface to a depth of 5 or 6 km. First-motion patterns suggest slippage along two main sets of nearly vertical surfaces, one parallel to the San Andreas fault and the other approximately north trending.
R. M. Hamilton studied aftershocks of the 1968 Borrego Mountain earthquake, the largest shock in California in over 15 years. Locations for more than 500 aftershocks, determined from data provided in part by C. R. Allen and J. N. Brune (both of California Institute of Technology) show that activity generally occurred within several kilometers of the fault break, although the locations did not define a simple zone as they did for the Parkfield-Cholame sequence. Focal depths ranged from near the surface to about 13 km, a maximum depth similar to that found in other studies they did for the Parkfield-Cholame sequence. Focal activity was within several kilometers of the fault break, although earthquake activity along the San Andreas fault system. First-motion patterns are generally consistent with right-lateral strike-slip movement in the direction of observed faulting. Data from a seismic refraction experiment carried out in conjunction with the aftershock study of the Borrego Mountain earthquake yielded baseline depth estimates for the area southwest of the Salton Sea.

These microearthquake studies indicate that earthquake activity along the San Andreas fault system is, in contrast to many other seismically active areas, confined to the upper 15 km of the crust. This may arise from depth variations either in the mechanical properties of crustal rocks or of crustal movements.

A study by A. M. Pitt of aftershocks of the 1968 southern Illinois earthquake, carried out with Rev. William Stauffer (St. Louis University) produced results significantly different from the San Andreas studies. Only two aftershocks were detected, and one of these was at a depth of 25 km.

**Crustal strain and fault creep**

Deformation of the earth's crust along the San Andreas fault system was monitored by repeated geodetic observations at many sites from the San Francisco Bay region southeast to Cholame Valley, and in the Salton Sea area of southern California. Installations include 6 trilateration-triangulation networks and 7 alignment arrays to measure horizontal ground movement, and a level line to detect vertical deformation. In addition, a tiltmeter is operated at San Francisco.

Observations on alignment arrays on the San Andreas fault between San Juan Bautista and Cholame Valley by R. O. Burford yielded the most extensive set of fault-creep data ever compiled for a 6-month interval. The largest offset, 2.4 cm, was recorded at Slack Canyon, about 28 km northwest of Parkfield, at an average rate of 4 mm/month. This is the highest rate of fault creep ever recorded on the San Andreas fault except for creep recorded in Cholame Valley by the U.S. Geological Survey and others immediately after the 1966 Parkfield-Cholame earthquakes. The magnitude of creep decreased in both directions away from Slack Canyon, but remained at a level of approximately 1.7 mm/month as far as Melendy Ranch, 76 km to the northwest of Slack Canyon.

Changes in elevation along a level line at San Andreas Lake, on the San Francisco Peninsula, show substantial vertical movement across the San Andreas fault zone. The northeast side moved down about 2 cm in 3 months relative to terrain on the southwest side at a distance of about 1.1 km. The record of strain changes on lines in the San Andreas Lake trilateration-triangulation array indicates a possible strain cycle of about 24 months' duration. The predominant strain component is areal dilatation, which accumulated steadily during an 18-month period to a level of approximately +1/10^8 before the onset of a short-term strain event characterized by negative dilatations and higher shear. Typical rates of extension for lines in the array are in the range 1 to 3 parts in 10^10 per month, or 1 to 4 parts in 10^8 per year, an order of magnitude higher than expectations based on analysis of older triangulation data compiled for active fault zones by the U.S. Coast and Geodetic Survey.

**GEOLOGIC STUDIES**

**Borrego Mountain, Calif., earthquake**

Significant new results were obtained through studies of the Borrego Mountain, Calif., earthquake of April 8, 1968. This 6.5-magnitude earthquake was located on the Coyote Creek fault, within the southern, complexly splayed part of the San Andreas fault system. Field investigations (C. R. Allen and others, r1855) were begun immediately after the earthquake and were jointly conducted by scientific teams from the California Institute of Technology and the U.S. Geological Survey. M. M. Clark and Arthur Grantz report that 31 km of newly formed en echelon and single fractures along the Coyote Creek fault demonstrate right-lateral displacement of as much as 38 cm. Apparent vertical separation along the fault is as much as 22 cm, generally in such a sense as to reinforce preexisting topographic irregularities. Although most of the displacement was confined to a zone 1 to 20 m wide, minor fractures were found as far as 3 km from the main fault break. In March of 1969, Clark and Grantz found that some fractures along the southern segment of the Coyote Creek fault had increased in size, indicating continued creep on the fault. Some of these fractures also had collapsed into voids eroded along them at depth by surface runoff. The runoff followed the fractures downward into porous beds and into voids created in the process of fracturing. This collapse cre-
ated sinks ranging up to a few meters across, 2 m or more deep, and 100 m long at some of the fractures.

After the Borrego Mountain earthquake, Grantz and R. E. Wallace, working with Caltech geologists and seismologists, found evidence of nearly contemporaneous creep on other nearby faults in the San Andreas fault system. Creep with little or no accompanying seismic activity was identified and mapped on the Mission-Banning, Imperial, and Superstition Hills faults at points as distant as 70 km from the epicenter of the main earthquake. These remote fault movements suggest the possibility that a major earthquake may trigger a sequence of tectonic adjustments on a number of related faults within a strained portion of the earth’s crust.

The creep event on the Mission-Banning fault that occurred about the time of the Borrego Mountain earthquake had been preceded by similar events in previous years. Wallace found older en echelon fractures along the fault which had been eroded and modified. Some of the older fractures had collapsed as a result of surface runoff flowing into the cracks and through channels created by the fractures.

**Dating faults by tree rings**

Identifying and dating prehistoric but geologically young (Holocene) fault movements is a critically important but difficult area of research. Observations by R. E. Wallace near the type locality of the San Andreas fault on the San Francisco Peninsula suggest that dendrochronologic techniques may help fill gaps in the record of recent fault movements. Wallace found that trees growing in and along the 1906 fault break record evidence of interrupted growth both in their morphology and in their growth rings. These growth interruptions were dated by the tree-ring chronology and were found to indicate damage occurring in 1906. Injuries that caused the growth interruptions are ascribed by Wallace to (1) fault disruption of the entire root system, (2) fault-induced changes in the ground-water level, and (3) tilting, where newly formed fault scarps weaken, cut, or otherwise adversely affect part of the root system and render a tree susceptible to disruption by wind or sliding of water-saturated earth. Reconnaissance investigations are now underway to further evaluate dendrochronologic evidence of fault movements, and to attempt to identify pre-1906 fault movements by this approach.

**Studies of San Andreas and related faults, California**

The search for geologically young but datable fault movements, like those recorded by tree growth, is considerably facilitated by a new series of maps which show the location of the most recently active breaks along the fault. The first of these, by D. C. Ross (r2206), shows recently active breaks along the San Andreas fault between Cajon Pass and Tejon Pass in southern California. Similar maps will cover the San Andreas fault zone from near the international boundary with Mexico, north to Shelter Cove near Cape Mendocino; compilation and field verification has been completed for all parts of the fault from San Juan Bautista south.

Geologic and historical evidence noted on the strip maps shows that major earthquakes recur on the San Andreas fault. The frequency of recurrence is difficult to determine because historical fault movements and earthquakes (which can be precisely dated) are relatively few and because the much more substantial aggregate fault movements of the geologic past cannot be precisely dated or separately distinguished. Nevertheless, determination of recurrence rates may provide accurate knowledge that could significantly affect the planning and design of structures as well as the future development of large areas along the fault zone. R. E. Wallace (r0956) suggests that, along the San Andreas fault, recurrence intervals between earthquakes of a given magnitude are related to (1) long-term offset rates since mid-Tertiary time, (2) displacements and lengths of breaks recorded for historic earthquakes, and (3) tectonic creep rates. He relates these as

\[ R_x = \frac{D}{S-C} \]

where

- \( R_x \): recurrence interval of an earthquake of a given magnitude at a point given on the fault,
- \( D \): displacement (related empirically to Richter magnitude),
- \( S \): long-term strain rate (from offset of geologic units), and
- \( C \): tectonic creep rate (related empirically to Richter magnitude).

A variation of this analysis provides a means of determining the recurrence interval for the entire fault if the total fault length is known and if the length of fault break associated with an earthquake of any specified Richter magnitude is known. Wallace’s analyses are based in part on observations that tectonic creep rates along the San Andreas fault appear to be inversely related to the Richter magnitude of earthquake activity; that is, creeping segments of the fault seem to exhibit no evidence of large earthquakes, and segments with a history of great earthquakes exhibit little or no tectonic creep.
Evidence of older tectonic activity in the San Andreas system continues to accumulate and to substantiate the relative northwestern drift of the continental margin west of the San Andreas. Typical of such evidence is that found along the San Andreas fault in the Carrizo Plain area, where field relations in clastic rocks of middle Miocene age were previously described by H. E. Clifton. Clifton showed that rocks immediately west of the San Andreas fault must have been derived from a nearby source to the northeast. Because he found no evidence that this source now underlies nearby areas across the fault, he deduced that the source was tectonically displaced by right-lateral movement west of the San Andreas fault. This interpretation has been further substantiated by H. C. Wagner and J. A. Bartow. Their investigations of subsurface geology are based chiefly on analysis of drill-hole information and confirm the northeastward increase in thickness and grain size in nonmarine rocks of middle Miocene age as suggested by Clifton. They find that rocks immediately across the fault to the northeast are of the same age (middle Miocene) but are marine and were deposited at bathyal depths—as is shown by the microfaunal studies of R. L. Pierce. Thus juxtaposition at the fault of rocks of exactly the same age but of entirely different facies or modes of origin (that is, continental and nonmarine) derived from a source with high relief versus deep-water, open-ocean marine sediments) cannot be explained by vertical tectonics and is best satisfied by strike-slip movement on the order of about 160 km. In this area, as elsewhere along the San Andreas fault, meaningful tectonic analysis depends on many kinds of geologic evidence; here, for example, essential data were derived from (1) detailed field mapping of rock units and structures, (2) stratigraphic analysis and sedimentologic interpretation of paleoenvironment, (3) detailed analysis of subsurface geologic data, and (4) paleontologic determinations of both age and paleoenvironment.

Clues that may eventually help scientific investigators understand the early history and origins of the San Andreas fault were uncovered by D. C. Ross in his study of basement rocks that are cut by the fault. Ross reports that rootless masses of a highly distinctive hornblende-quartz gabbro occur at Logan near the northern edge of the Gabilan Range and also at Gold Hill, about 160 km to the south. Both localities are in the San Andreas fault zone, and the rocks at both are not only unusual but chemically and petrographically very similar; these relations suggest to Ross that the rock masses were once joined and have been separated by lateral fault movement of at least 160 km. An indication of even greater displacement (240 km) is found in anorthosite and anorthositic gabbro, which also lie in the fault zone at the Logan locality. These distinctive rocks may be the source of boulders of similar lithology found in conglomerate of Cretaceous age in the Gualala area 240 km along the San Andreas fault to the northwest.

W. F. Hanna, S. H. Burch, and T. W. Dibblee, Jr., have jointly analyzed magnetic, gravity, and geologic data along a 25-km segment of the San Andreas fault near Cholame, Calif. Their use of three independent sets of data greatly reduces the amount of interpretive ambiguity in this structurally complex area and permits them to draw the following relatively firm conclusions about: (1) the configuration and distribution of Franciscan rocks northeast of the fault—they are near surface and are deformed along northwest-trending structures that approximately parallel the San Andreas fault; (2) the nature of the Table Mountain serpentinite body—a thick, steeply dipping, dikelike body, not a subhorizontal sheet as previously interpreted; (3) the northeastward extension of Franciscan rocks and associated ultramafic rocks northeast of the fault—they appear to be truncated in this direction by a major northeast-dipping subsurface discontinuity; and (4) a major magnetic anomaly near Palo Prieto Pass south of Cholame—it appears to be caused by a buried serpentinite body located along the northeast side of the San Andreas fault and about 3 km deep. Detailed geologic analysis of this area is especially valuable because the area lies at the southern end of that part of the fault which appears to be creeping at a generally uniform rate of about 2 cm/yr and at the northern end of the "locked" segment of the fault which last moved during the great 1857 earthquake.

The northern extension of the San Andreas fault system is uncertain beyond Cape Mendocino, where it appears to end at or near the continental margin and approximately on line with the trend of the Mendocino escarpment. The oceanic part of the west-trending, south-facing Mendocino escarpment is not only a major sea-floor topographic feature, but on gravity, magnetic, and seismic evidence it also appears to be a major fault and to juxtapose segments of crust and upper mantle with markedly different properties. Andrew Griscom reports that gravity surveys of an area about 15,000 sq km inland from Cape Mendocino show no indication of an eastern onshore prolongation of the Mendocino escarpment. This evidence places important constraints on theories relating oceanic and continental
tectonics and thereby significantly affects geological interpretations of the mechanics of the San Andreas fault system.

Relations at the opposite end of the San Andreas fault system are also somewhat uncertain, for south of the mouth of the Colorado River the main branches of the fault appear to trend into the Gulf of California. Related faults with substantial Holocene and even historical right-lateral movement are known in northern Baja California, and studies of these may contribute much to understanding earthquake problems in the San Andreas fault system. W. B. Hamilton has analyzed vertical photographs of this area taken from the unmanned Apollo 6 space vehicle. The photographs exhibit evidence that north-trending Valle San Felipe is a tensional rift and that the west-northwest-trending right-lateral Agua Blanca fault bears a transform relation to the normal faulting that bounds Valle San Felipe.

Recent tectonic activity in Alaska

Field investigations in Alaska continue to provide new evidence of recent tectonic activity and surface fault movements. Near Yakutat in south-central Alaska, George Plafker's geologic mapping extended the known location of the Fairweather fault northwestward through Nunatak Fiord and across Hubbard Glacier. Recent scarps and en echelon fissures along a northwest-trending strand of the fault near Hubbard Glacier show about 1.3 m of right-lateral separation and as much as 1 m vertical separation with the southwest block relatively upthrown. The displacement is in the same sense as that observed along the Fairweather fault, some 210 km to the southwest, after the July 10, 1958, earthquake; moreover, the scarps appear fresh enough to have been formed then. A segment of the Fairweather fault parallels the Nunatak fault in Nunatak Fiord where Tarr and Martin interpreted offsets along a northwest-trending fissure zone as apparently anomalous left-lateral oblique-slip movements at the time of the great Yakutat Bay earthquakes in 1899. Plafker's detailed study of the Nunatak fault and reevaluation of the Tarr and Martin data suggests that the fissures result from local crustal warping, from gravitational sliding, or from both, and that they are not directly related to faulting.

Earthquake studies overseas

Overseas, an increasing concern for the hazards of earthquakes and modern fault activity has improved the interchange of geologic information related to

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these topics. In July 1968, the Conference on Earthquake Hazard Minimization, in Ankara, Turkey, under the sponsorship of the Central Treaty Organization (CENTO) brought together experts with widely varied backgrounds from all five CENTO countries. Geologists, structural and civil engineers, seismologists, planners, architects, soil scientists, and administrators examined methods by which the dangers of earthquakes in Turkey, Iran, and Pakistan might be minimized. R. E. Wallace assisted in organizing the conference and served as technical advisor. He also outlined for the conference (R. E. Wallace, r2463) the four major geologic factors in earthquake hazard: faulting, unstable ground, influence of ground on shaking, and tectonic warping.

On August 31, 1968, shortly after the CENTO conference, a major (magnitude 7.3) earthquake struck Khorassan Province in east-central Iran, killing more than 10,000 people and devastating a number of towns and villages in the meizoseismal area. A geologic field investigation of this earthquake by R. D. Brown, Jr., was conducted with the cooperation and assistance of the Geological Survey of Iran. Brown and his Iranian colleagues found that the main shock resulted from movement on the Dash-i-Bayaz fault, a west-trending left-lateral fault that cuts and juxtaposes Jurassic and younger rock units. The continuous surface fault break formed on August 31 is about 16 km long with a maximum left slip of about 4 m. Reconnaissance along the fault and elsewhere in the meizoseismal areas disclosed a marked relation between intensity of damage and geologic foundation conditions; villages on thick alluvial deposits were heavily damaged, and even more intense damage occurred where ground-water levels were shallow. The investigation again underscored the need for more improved construction practice in the Middle East—a need that had been heavily stressed only 2 months earlier at the Ankara CENTO conference.

Faults studied by remote-sensing techniques

M. M. Clark's evaluation of remote-sensing techniques underscored the value of special aerial photography in studies of active fault systems. Two types of aerial photography are especially noteworthy: (1) high altitude (scale 1:120,000 to 1:145,000) and (2) low sun angle (solar altitude 30° or less).

High-altitude photography has proved most useful in locating and delineating zones of recent faulting, largely because the lateral continuity (about 29 km) available in a single photograph permits easy inspection of a significant length of fault trace. Clark's work with this kind of aerial photography disclosed a pr-
Previously unmapped extension of the Coyote Creek fault in southern California; four months later the Borrego Mountain earthquake resulted in surface faulting along this segment of the fault, verifying not only its existence but its currently active nature. Similar high-altitude photography, also under study by Clark, is providing new insight into tectonic patterns along the east front of the Sierra Nevada and along the Garlock fault.

Low-sun-angle high-altitude photography appear to enhance topographic fault-line features on the Garlock fault and to permit much better definition of the fault than is possible with conventional aerial photographs. The successful application of low-sun-angle photography suggests a number of useful applications in earthquake and active fault studies. J. V. Tanida has accordingly revised a map-generating program so that computer-produced stereographic projections will show the azimuth and altitude of the sun for any time, date, and latitude. Using these data, researchers can schedule aerial photographic missions to obtain optimum lighting for geologic studies on any structure (or other geologic feature) of known trend.

ENGINEERING GEOLOGY

Comparison of strong ground motion and geology for the 1933 Long Beach, Calif., earthquake

A crude isoseismal map for the 1933 Long Beach earthquake in California was prepared by C. M. Wentworth and J. M. Buchanan from published descriptions of damage. The map was then compared to gross geologic features of the Los Angeles area to provide a basis for the rough prediction of the areal distribution of severe ground motion that might accompany a future earthquake. It was found that damage of intensity VI or greater from the 1933 earthquake was largely restricted to areas of post-Miocene sediments or sedimentary rocks. However, correlation is not evident between damage intensity and either depth to the water table or to the thickness of unindurated or poorly indurated sediments, thickness assumed to be the depth to the base of fresh-water-bearing sediments.

URBAN AND SPECIAL ENGINEERING STUDIES

Landslides at Rapid City, S. Dak.

Geologic mapping by J. M. Cattermole of the Rapid City East quadrangle, South Dakota showed that landslides are most common on north-facing sloped underlain by the bentonitic shales of the Cretaceous Pierre and Mowry Shales or the Belle Fourche Formation. Prehistoric slides that have been reactivated within Rapid City have caused considerable property damage. Similar slides, now apparently inactive, lie along the north side of an east-trending escarpment east of Rapid City. Future urban development should avoid this escarpment, as well as other steep north-facing slopes in bentonitic shale formations.

Use of engineering geology studies in Denver, Colo., land planning

Under a cooperative project with the Denver Regional Council of Governments, M. E. Gardner and C. G. Johnson are producing engineering-geologic maps of the Denver-Boulder area of Colorado (for example, M. E. Gardner, r1750) which can be interpreted and used directly for land-use planning by city and county officials, urban planners, subdivision developers, engineers, and builders lacking geologic training. Discussions with city and county officials to emphasize local geologic conditions of engineering importance are already proving beneficial. A precedent was set by Jefferson County planning officials in the platting of a subdivision where landslide deposits have been mapped. The planning officials suggested that the developers retain a private consultant to make a more detailed geologic investigation. As a result, the part of the tract on the landslide deposit was withdrawn from development because of potential instability. The awareness and consideration of geologic conditions relative to residential subdivisions are growing among home owners as well as legislators and local administrators, largely through the efforts of county planning officials and news media which cover the activities of the planners.

Landslides on Pine Mountain, Ky.

Landslides along the south slope of Pine Mountain in southeastern Kentucky are related to bedrock geology, according to A. J. Froelich and others of the Middleboro, Ky., field office. Some of the landslides are caused by the sliding of blocks of sandstone and interbedded shale and siltstone down a dip slope on shale. A half-mile-wide part of another slide that had been stable for many years recently slid when the toe was cut into during highway construction. The old slide may have originated as a simple glide down the dip slope, but it probably was more complex.

Strata underlying the south slope of Pine Mountain include massive sandstone, carbonaceous siltstone, and thin beds of coal and underclay, all of Pennsylvanian age. They dip generally southeastward but flatten abruptly at the foot of the mountain and are nearly horizontal south of it. The Cumberland
River follows the flexure along much of Pine Mountain, and in many places streambank erosion undercuts the dipping beds.

These landslides have occurred and others may occur where the dipping strata are undercut by the Cumberland River or by construction work. Old, presently stable, slides may be reactivated when cut into by highway or other excavations. If local geologic conditions are known in advance, potentially unstable areas can be predicted, slide-prone localities bypassed, and construction planned to avoid disturbing naturally stable conditions.

**Rock stress determined from borehole probes**

Data from borehole stress probes installed in laboratory rock specimens, and others set into bedrock at the Colorado School of Mines experimental mine, have demonstrated the effect of geologic structure on stress distribution changes caused by excavation. T. C. Nichols, Jr., J. F. Abel, Jr., and F. T. Lee (p. C127-C132) noted that the stress changes occurring in a rock mass as the result of excavation are usually time dependent, and may extend to greater distances from the excavation boundary than is predictable by elastic theory. It was found that highly nonuniform stress fields can exist in a rock mass, and that stress-field boundaries are greatly influenced by large geologic discontinuities such as faults. It is inferred that the rock masses may contain locked-in stresses that are mobilized when the rock is disturbed. S. P. Kanizay has started laboratory testing directed toward adapting the borehole probe for use in unconsolidated sediments.

**Electrochemical induration of soils**

The engineering effects of electrochemical alteration of three dozen samples consisting of three soil types were studied by D. H. Gray (soils engineer, University of Michigan), and Julius Schlocker. One soil contained montmorillonite, another illite, and a third was a mixture of illite and montmorillonite. As a result of electrochemical treatment, induration, as measured by vane-shear and liquid-limit tests, took place in nearly all the samples. It was most pronounced in samples of high initial water content, high pH, and of montmorillonitic composition. X-ray diffraction analysis and selective chemical extraction show that aluminum is introduced as hydroxyl-aluminum bond between clay layers in montmorillonite, but is present as an exchangeable ion in the illitic soils. A significant increase in shear strength took place in most samples during a 30-day period after the treatment.

**INVESTIGATIONS RELATED TO NUCLEAR ENERGY**

**TEST-SITE STUDIES**

**Nevada Test Site**

The Nevada Test Site (NTS) in southwestern Nevada is the area within which the U.S. Atomic Energy Commission conducts most of its underground nuclear-explosion tests. Since the first underground nuclear explosion in 1959 the U.S. Geological Survey has made extensive studies on behalf of the Commission of the geology and hydrology of the NTS. The Geological Survey participates in the appraisal of the safety, engineering feasibility, and postshot effects of all explosions conducted at the NTS.

R. K. Blankennagel recently completed an evaluation of hydrologic conditions beneath Pahute Mesa, one of the principal test areas at the NTS. Most of the ground-water movement beneath the mesa occurs through interconnecting fault and joint systems in the volcanic rocks, although there is a minor amount of interstitial permeability in some of the tuffaceous rocks. Ground water beneath Pahute Mesa moves southwestern and southward toward discharge areas in Oris Valley and toward the Amargosa Desert via Oris Valley, Crater Flat, and western Jackass Flats. Some eastward movement probably occurs across the ground-water divide into Yucca Flat. The underflow, across a 15-mile underflow strip along the southern margin of the Mesa, is estimated to be 8,000 acre-feet per year. The ground-water system beneath the mesa is recharged by underflow from Kawich Valley and Gold Flat on the north, and from precipitation on the mesa.

Gravity surveys were successfully used by R. R. Wahl to delineate the buried surface of pre-Cenozoic rocks beneath Rainier and Aqueduct Mesas. Knowledge of the pre-Cenozoic surface is necessary to plan tunnels to avoid carbonate rocks of Paleozoic age. Wahl was able to map the buried pre-Cenozoic surface in sufficient detail to infer buried faults with throws of 450 and 1,100 feet.

Earthquakes triggered by nuclear explosions have been observed from high-yield explosions. F. A. T'Keown and D. D. Dickey made preshot and postshot geodetic strain net measurements on the surface as a method to study the release of tectonic strain by explosions and earthquakes. Their measurements demonstrate that the present tectonic stress in the NTS part of the Basin and Range province is compressional, not tensional as previously had been assumed. In addition, observed lateral movement on some basin-and-range-
type faults triggered by explosion tend to confirm compressional stress. D. B. Grove used the radiocarbon dating technique to estimate the velocity of ground-water movement beneath the NTS. He estimates an average ground-water velocity of 7 ft per yr. This compares with velocities of 7.3 to 730 ft per yr as calculated from measured values of transmissivity, hydraulic gradient, and porosity.

Central Nevada

The U.S. Atomic Energy Commission detonated the first underground nuclear explosion in Hot Creek Valley, northern Nye County, central Nevada test area, in January 1968. Subsequent tests are planned in 1970.

The U.S. Geological Survey has been involved in exploring potential test areas by drilling, geologic mapping, geophysical surveys, and hydrologic studies. The valley areas are of prime interest because of the thick accumulation of alluvium and volcanic rocks.

D. L. Healey used gravity surveys to estimate the combined thickness of alluvium and volcanic rocks in Hot Creek and Little Smoky Valleys. On the basis of 2,036 gravity observations he estimates the maximum combined thickness of alluvium and volcanic rocks to be 9,000 feet in Hot Creek Valley and 7,000 feet in Little Smoky Valley.

G. A. Dinwiddie studied the ground-water hydrology of Little Smoky Valley. He concludes from observations of ground-water gradients that the discharge area for the Hot Creek and Little Smoky Valleys is Railroad Valley to the east. Deep-hole hydraulic testing in Little Smoky Valley discloses that intervals of high hydraulic conductivity in the volcanic rocks are fracture related, and that some intervals of welded tuff have sufficiently low hydraulic conductivity to permit excavation of chambers to depths of 5,000 feet below the water table.

Amchitka Island, Alaska

The U.S. Geological Survey is continuing to study the geology and hydrology of Amchitka Island to assist the U.S. Atomic Energy Commission to develop the island for future underground nuclear explosions. Five deep (6,500-7,500 feet) exploratory holes have been drilled. Most of the rocks drilled consist of propylitized volcanic breccia, although one hole is in the contact-metamorphic aureole of an intrusive body in the central part of the island.

The island receives about 35 inches of precipitation per year, most of which is temporarily delayed in ponds and tundra before it discharges to the oceans from numerous small streams. Some water enters the rocks by seepage from ponds and tundra. Water levels in five exploratory holes range from land surface to 400 feet below land surface. The hydraulic potential decreases with depth. Water-level gradients range from 113 to 405 ft per mi in shallow zones and from 28 to 98 ft per mi in deep zones.

The hydraulic conductivity of the rocks on Amchitka Island is very low, except along zones of intense fracturing. At all but one of the exploratory sites, deep underground chambers for nuclear tests could be excavated without severe problems of water infiltration.

The Geological Survey has collected numerous ground and surface water samples on Amchitka Island for analysis. These preshot analyses will be compared with similar analyses after each nuclear explosion to determine and evaluate any changes in the water underground or on the surface of the island.

EARTH-ORBITING NUCLEAR GENERATORS

Equations developed by D. B. Grove could be used to predict the concentration of an ion in the ground-water environment as a function of time and distance. Should an earth-orbiting satellite containing a nuclear-powered thermoelectric generator plummet to earth, scientists could use the equations to determine the extent of contamination.

Chemical models developed for this purpose include the use of theoretical plates (layers), a kinetic nonequilibrium concept, and an equilibrium concept. The equilibrium model, presently used to predict radionuclide concentrations as a result of underground testing of nuclear devices, was chosen as the presently most acceptable model. The equation in one-dimensional form for this model is

$$c/C_0 = \frac{\text{erf} \left( \frac{x-Ut}{2\sqrt{D_m}Ut} \right)}{2} - \frac{\text{erf} \left( \frac{x-Ut'}{2\sqrt{D_m}Ut'} \right)}{2\sqrt{D_m}Ut'},$$

where

- $c$ = concentration of tracer solute in the mobile fluid phase,
- $C_0$ = ionic concentration of tracer in initial solution,
- $D_m$ = dispersion constant,
- $x$ = distance,
- $t$ = time since contact with ground water,
- $t' = t - \Delta t$,
- $\Delta t$ = length of tracer slug in terms of time of transit,
- $U$ = average velocity of ion = water velocity/retardation factor owing to ion exchange,
- $\lambda$ = radioactive decay constant,
- exp = exponent (natural log base), and
- erf = error function.
RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Radioactive materials in suspension or solution are discharged to the hydrologic environment as a result of the operation of a wide variety of nuclear-energy facilities. The research on this subject is sponsored by the U.S. Atomic Energy Commission, and is related primarily to the transport of these materials through the hydrologic cycle. It would also be applicable to predicting the fate of radioactive materials that might be released to the hydrologic environment in the event of an accident.

Part of the research and investigation is devoted to protecting the hydrologic environment from contaminating solutions that might be derived from disposed solid or liquid wastes, and part is related to new waste-disposal methods and techniques.

Columbia River and estuary

A study of the occurrence and transport in the lower Columbia River of radionuclides derived from the U.S. Atomic Energy Commission's Hanford reactors was made by W. L. Haushild and H. H. Stevens, Jr. They computed weekly inventories of radionuclides in the channel sediments between Pasco, Wash., and Vancouver, Wash., from January 1964 to September 1966. The inventory data indicated than an equilibrium between the river system and the radionuclide input, which started in the mid-1940s, has been attained. A comparison of trends in the inventories with trends in the radionuclide input during the record period shows that uptake capacity of the channel sediments probably exceeded the supply for zinc-65, cobalt-60, cobalt-58, and manganese-54 and was probably less than the supply for scandium-46, iron-59, antimony-124, and chromium-51. Time-distribution data indicate that (1) chromium-51 and antimony-124 minimums generally coincide with the annual peak water discharge in June, and (2) inventories for other radionuclides are at a minimum during the recession period for the water discharge, from July to August. Inventories generally are at a maximum in October and November for chromium-51, and from March to May for zinc-65 and antimony-124. The inventories for cobalt-60 and iron-59 are greater from March to May than in October and November. For many radionuclides, the March to May inventory maximums coincide with maximum concentrations in the water and suspended sediments. Other investigators have found that concentrations of many stable elements in the Columbia River are also at a maximum during the March to May period.

D. W. Hubbell and J. L. Glenn indicated that in June 1965 the total amount of artificially produced radioactivity residing in the bed of the Columbia River estuary between the mouth (mile 0) and Longview, Wash. (mile 66) was about 8,700 curies. Approximately 24 percent of the total was zinc-65, and most of the remainder was chromium-51. Nearly half the total activity was located in the reach between mile 8 and mile 23, where the estuary is widest and the total activity per unit area of bed was the greatest. The depth of activity in the bed ranged from only a few inches to depths in excess of 6 feet and averaged about 2.7 feet throughout the estuary.

J. L. Glenn found from statistical studies of variations in radioactivity in four environments of the estuary near Astoria, Oreg., that significant changes occurred during the year. A relation with the annual upland flow pattern is suggested.

High-resolution subbottom acoustic profiling coupled with side-scan sonar records obtained in September 1968 have shown details of the stratigraphy and geomorphology of the Columbia River estuary. Subbottom profiles clearly show areas of the main channel in the upper part of the estuary (above Harrington Point, mile 23) where dunes as much as 18 feet high are moving over bedrock. Side-scan sonar records, in addition to differentiating sand, mud, and bedrock, show patterns of sediment transport in different types of channels by their three dimensional portrayal of bed forms.

A brief reconnaissance of the extent of concentration of radioactivity in selected invertebrates in the lower Columbia River was made by R. L. Cory and J. V. Nauman. Two species of fresh-water mussels, Anodonta wahlamentensis and A. oregonensis, and the clam, Corbicula fluminea, were found in varying abundance in the protected sloughs and along banks of islands. All three species concentrate radioactive trace metals. The concentration of zinc-65 was highest in C. fluminea, with average values of about 3,700 pCi/g of ash as compared to 2,200 and 1,500 pCi/g of ash in A. wahlamentensis and A. oregonensis, respectively. The average concentration of chromium-51 was about 3,600 pCi/g of ash in C. fluminea, 900 in A. wahlamentensis, and 500 in A. oregonensis. A pictogram of average total radioactivity and specific activity of zinc, manganese, and chromium revealed distinct differences in concentrations between the three species studied.

Infiltration pond in playa silts and clays

In connection with the design of a radioactive waste-disposal pond in playa sediments at the National Reactor Testing Station, Idaho, W. E. Teasdale and R. G. Jensen studied the evaporation and infiltration rates of playa silts and clays. Two excavated pond
were instrumented, and a double-ring infiltrometer and evaporation pan were installed. The average infiltration rate for shallow ponds in the playa sediments was 0.1 to 0.3 ft per day. Little difference in the infiltration rates of tap and salty water was noted during short tests. The results of these tests are being used to design a waste-disposal pond capable of utilizing some of the sorptive capacity of the sediments.

**Underground disposal of radioactive gases**

J. B. Robertson analyzed the diffusion of gas from a gas injection test conducted jointly by the U.S. Atomic Energy Commission and its contractors, and by the U.S. Geological Survey, at the National Reactor Testing Station, Idaho. One million cubic feet of air containing 987 curies of xenon-133 were injected at a depth of 120 feet into permeable basalts capped by fine-grained playa sediments. Using a mathematical model and a digital computer it was estimated that 0.37 curie could have diffused from the basalt rocks through the capping sediments into the atmosphere during the 25 days following the injection. Diffusion rates as high as $3.5 \times 10^{-5}$ curie per hr per sq ft were calculated. The calculated rates generally agreed with the measured rates. Diffusion losses would amount to only 0.04 percent of the 956 curies lost by radioactive decay in the 25 days. A materials-balance analysis for the injected xenon-133 was calculated using measured subsurface concentration data and an effective porosity of 5 percent for the basalt. The decline curve for the calculated inventories was parallel to the radioactive decay curve, but it was 1 order of magnitude lower. It was concluded that the measured subsurface concentrations were erroneously low by a factor of 10, and this conclusion was later verified by other evidence.

The effects of barometric pressure changes on the injection test were estimated for maximum and minimum conditions. Calculated vertical gas-flow rates induced by atmospheric pressure changes show that this mechanism could be more significant than the molecular diffusion effects, at certain times and locations, but that it had little effect on most of the injected xenon-133. It was concluded that almost all the injected gas remained underground and decayed radioactively.

**Waste disposal by hydraulic fracturing and grout injection**

A key factor in evaluating the suitability of sites where slurries of grout and radioactive wastes can be injected into hydraulically induced fractures is the certainty with which the orientation and extent of the fractures can be predicted. This is vital with respect to isolating the radioactive wastes from the hydrologic environment. R. J. Sun developed a mathematical model for calculating the size of hydraulically induced horizontal fractures and the corresponding amount of land-surface uplift produced by injection into an impervious, homogeneous, and isotropic medium. The calculated amount of uplift agreed reasonably well with observed data from nine waste-grout injections made at the Oak Ridge National Laboratory, Tennessee.

**SITES FOR NUCLEAR POWER REACTORS AND OTHER FACILITIES**

In the selection and development of sites for nuclear power facilities, it is vital in the interest of public safety to thoroughly understand and evaluate certain aspects of the regional and local geology and hydrology. In connection with the construction and licensing of nuclear power facilities by the U.S. Atomic Energy Commission, potential or actual geologic hazards are reviewed by the U.S. Geological Survey with regard to the engineering design of the installations. Also reviewed are such hydrologic characteristics of the sites as the adequacy of protection from extremely damaging floods, the dependability of water supplies for cooling condensers, and the possible extent of contamination of water resources through the operational or accidental release of radionuclides.

During the year H. H. Waldron, E. L. Meyer, and P. J. Carpenter reviewed the engineering geologic and hydrologic aspects of more than 30 proposed nuclear power plants and other nuclear facilities.

**Extreme hydrologic events and their effects on nuclear facilities**

P. H. Carrigan, Jr., in analyzing hydrologic factors affecting the suitability of sites for nuclear installations, studied the statistical occurrence of extreme events. He found that annual floods, contrary to the common assumption that they are independent, may exhibit autocorrelation under conditions of high base flows. Also, annual flood series are free of trends and cycles. The number of floods per year exceeding a selected magnitude follows a Poisson distribution (p. B162-B163).

Simulation techniques were developed for estimating the recurrence interval of rare hydrologic events, for instance the 200-year flood, and for determining the probability of a water-supply reservoir emptying in $N$ years ($N=1, 2, 3 \ldots 100$). Estimating the recurrence interval of rare events requires pooling regional annual flood experience in the computer simulation technique. The probability of a reservoir emptying—if one assumes a constant draft and serially correlated log-normally distributed inflows—is a function of the mean, coefficient of variation, and correlation coeffi-
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 discussions of outstanding floods of 1968–69, flood frequency, and flood mapping.

OUTSTANDING FLOODS OF 1968–69

Floods of April 1968 at Many, La.

An almost stationary line of thunderstorms from 50 to 75 miles wide produced up to 12.5 inches of rain on April 8–9 in the Many, La., area. Runoff from Harpoon Bayou, Phillips Creek, Blackwell Creek, and San Jose Creek inundated large areas surrounding Many and virtually isolated the town. The inundated areas have been delineated on a photomosaic map in Hydrologic Investigations Atlas, HA-374, by A. S. Lowe. Hydrologic data can be used to evaluate the magnitude and frequency of flooding in the area.

Floods of May 1968 in southern Ohio

E. E. Webber reported that heavy rains on May 23–24 and on May 27–28 resulted in severe flooding in streams in southern Ohio. From 5 to 7 inches of rain fell in 24 hours and produced floods having recurrence intervals of more than 50 years on some streams in the basins of the Hocking, Scioto, and Little Miami Rivers. Two persons drowned, and 20 counties were declared flood-disaster areas. About $1 million damage was done to roads, crops, livestock, and homes.

Floods of January and February 1969 in southern California

Extremely severe floods occurred in southern California from two storms, one in January and one in late February. The storm of January 17–27 brought from 12 to 28 inches of rain throughout the State. Precipitation was heaviest in the Coastal Ranges. The Sierra Nevada also received heavy precipitation which consisted principally of snow at altitudes above 7,000 feet. Maximum peak discharges of record occurred from Monterey County southward to Los Angeles. About 100 lives were lost. In addition to flood damage to homes, businesses, roads, bridges, citrus groves, and cropland, about 130 houses were destroyed by mudslides in the Glendora area (13 miles east of Pasadena). Damage from the January floods was estimated at more than $150 million. The President declared the State a disaster area.

While the soil was still saturated from the January storm, other severe storms occurred on February 23–24 in the same area in which the January floods had occurred. Mudslides and landslides continued, and 10,000 persons were evacuated from their homes in southern California and the San Joaquin Valley. Floodflows generally exceeded those of January in San Bernardino, Riverside, Orange, and San Diego Counties. Flows in most streams north of Los Angeles were generally equal to or less than those in January. Severe flooding in the Fresno and Madera areas and in the San Joaquin Valley resulted from heavy runoff from the Sierra Nevada foothill streams and from the breaching of canals and levees. The February floods caused great destruction of roads, bridges, and residential and industrial properties.

Floods of January–February 1969 in Arkansas and southern Missouri

Near the end of January, heavy rains of as much as 10 inches in Arkansas and southern Missouri caused severe flooding lasting until early February. The most severe floods were in Arkansas, and peak discharge on at least two streams was greater than the maximum likely to occur on the average of once in 50 years. Seven lives were lost, and damage to homes, businesses, roads, and bridges was estimated at more than $5 million. The President declared 32 counties a disaster area.

Floods of April–May 1969 in upper midwestern United States

Heavy accumulations of the winter snow (in some places record breaking) set the stage for great floods in the upper Mississippi River basin in southern Minnesota, southeastern North Dakota, eastern South Dakota, and northwestern Iowa, and in the Red River of the North basin in Minnesota and North Dakota. Warming temperatures of spring, sometimes accompanied by rain, completed the act.

The flood area corresponded to the area of high-water equivalent of the accumulated snow. The greatest water equivalent was 10 inches in southwestern Minnesota and as much as 8 inches in adjacent parts of Iowa and South Dakota. Water equivalent in central-western Minnesota was 8 inches and in adjacent areas of North Dakota it was from 4 to 6 inches. There was as much...
as 8 inches of water equivalent in the snow in the Souris River Loop in North Dakota. Because of low temperatures in early spring, intermittent thawing and freezing did not occur, and when warm weather arrived it caused continuous buildup of runoff. Many maximum discharges of record occurred throughout the flood area, and a great number of peak discharges exceeded 50-year floods. Flood damage was widespread, concentrated principally in cities along large streams and has been estimated at $100 million. Eight lives were lost, all in Minnesota.

**Floods of May 1969 in northeastern Colorado**

As much as 10 inches of rain fell on May 4-7 in northeastern Colorado along the eastern Front Range and foothills of the Rocky Mountains from Estes Park on the north to Conifer in the south and extended eastward into the South Platte River valley. The rain resulted in extremely damaging floods in the area. Discharges in the South Platte River were high and exceeded a 50-year flood in some places. Most roads in a canyon area from 10 miles south of Denver to about 30 miles north of Denver were extensively damaged from rock slides and washouts. Several houses in Jamestown were destroyed by the flooding Left Hand Creek. Several houses in Denver were damaged by floodwaters from the South Platte River and Bear Creek. Low-lying farmland was flooded along the South Platte River from Denver to the Nebraska State line. Flood damage was estimated at more than $7 million.

**FLOOD-FREQUENCY STUDIES**

**Nationwide flood-frequency project**

The final three volumes of the 19-volume nationwide flood-frequency series were published this year: Water-Supply Papers 1673 (R. H. Tice, r0835), 1678 (J. L. Patterson, and C. R. Gamble, r1492), and 1680 (H. F. Matthai, r0836).

**Magnitude and frequency of Virginia floods**

A statistical analysis of flood peaks on unregulated streams in Virginia by E. M. Miller (r1236) shows that the dominant independent variables affecting flood-frequency relations for Virginia streams are size of drainage basin and slope of the stream. From data in the report the mean annual flood can be used as an index to which floods of other recurrence intervals can be related in terms of dimensionless ratios.

**Water-surface profiles of flood peaks in Polk County, Oreg.**

Profiles of the 2-, 10-, and 50-year floods, and the December 1964 floods were computed by C. H. Swift III and E. A. Oster, using step-backwater methods, for a 24.2-mile reach of the Luckiamute and Little Luckiamute Rivers. Comparison of the computed profile of the flood of December 1964 to observed high-water marks suggests that the natural berms along the channel may reduce the effective conveyance of the flood plain.

**Sewage lagoons increase flood elevations**

K. V. Wilson reports that the construction of sewage lagoons on the relatively flat, wide valleys of streams in Mississippi has been found to significantly increase flood elevations. Step-backwater computations along Leaf River at Hattiesburg indicate that the 50-year flood elevation has been increased a maximum of 1.5 feet by lagoon construction. Construction of lagoons along Oldtown Creek near Tupelo and Tallahala Creek at Laurel indicates an increase of about 1 foot. These increases in elevation are particularly significant because they occur in residential and commercial areas.

**Change of flood-flow characteristics by flood-control dams**

K. V. Wilson reports that analysis of flood data of Tippah River in Mississippi (before and after construction of flood-control dams and channel rectification) reveals a considerable change in flood-flow characteristics. Although floodflow from more than 30 percent of the 359-sq mi drainage basin near Potts Camp is controlled by dams, channel rectification has increased peak discharges of small floods. T° velocities in the rectified channels were greatly increased over those in the natural channels, and large sediment loads result from scour of channel banks.

**FLOOD MAPPING**

**Flood-inundation maps of urban areas**

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: McHenry, Ill. (R. T. Myck and G. L. Walter, r1386); Woodstock, Ill. (H. E. Allen, r1422); Beecher West, Ill. (H. E. Allen, r0403); Arecibo, P.R. (I. J. Hickenlooper, r2325); Mayaguez, P.R. (I. J. Hickenlooper, r1209); Vega Alta and Vega Baja, P.R. (I. J. Hickenlooper, r1707); Norwich, I.'Y. (Stephen Hladio, r1057); Dwyer, Ill. (H. E. Allen, r1059); Beecher East, Ill. (H. E. Allen and A. W. Noehre, r2209); Wilton Center, Ill. (H. E. Allen and A. W. Noehre, r1704); Waimanalo, Oahu, Hawai'i (Reuben Lee and W. C. F. Chang, r1060); Carlsbad, N. Mex. (L. P. Denis, r1061); Boone, N.C. (W. J. Haire, r0723);
Amesville, Ohio (R. I. Mayo and E. E. Webber, r2212); Jackson, Ohio (E. E. Webber and R. I. Mayo, r2213); Craig County, Va. (D. H. Rapp, r2215); Salyersville, Ky. (C. H. Hannum, r0152); and West Jefferson, N.C. (W. J. Haire, r2505).

Floods on Rock River in northern Rock County, Wis.

J. O. Shearman determined the area that would be inundated by the regional (100-year) flood for a 12-mile reach of the Rock River between Janesville and Lake Koshkonong in Wisconsin. Computed water-surface elevations for the regional flood are 8 to 14 feet higher than normal low-water elevations and 3.8 to 5.8 feet higher than the elevations of the 1959 flood (highest discharge since at least 1929).

Flood-inundation maps of Nashville, Tenn.

L. G. Conn reported that flood-inundation maps have been prepared for most of the Browns Creek basin in Nashville, Tenn. The maps show areas that will be inundated by specific floods under present conditions and areas that would be inundated after development of the basin as forecast by the Metropolitan Planning Commission.

Flood-inundation maps at Cedar Rapids, Iowa

Maps and water-surface profiles by H. H. Schwob (U.S. Geological Survey, r2564) illustrate the potential flood-plain inundation for a great flood on Squaw Creek (drainage area, 14.6 sq mi). Flood profiles are also shown for a smaller flood. The study area is near the eastern edge of Cedar Rapids in a region of probable urban development.

Flood-prone areas mapping project

Advantage was taken of the experience gained last year in the pilot project of a mapping program for flood-prone areas in accordance with House of Representatives Document 465. Thirty districts participated in the program; 1,475 maps, including revision to maps prepared under the pilot project, were completed and printed during the fiscal year.

WATER QUALITY AND CONTAMINATION

The development and use of water in many areas are restricted or complicated by the presence of undesirable waste products and natural constituents in surface and ground waters. To study these undesirable water contaminants, the U.S. Geological Survey conducts basic research and areal investigations that define the causes and the extent of contamination in the natural environment.

Pesticides in surface water of the Western United States

Selected streams in the Western United States were monitored for pesticides in solution during the period October 1966 to September 1968. The original network of 11 sampling stations was increased to 20 in October 1967. In studies reported by D. B. Manigold and Jevn Schulze each monthly sample was analyzed for the insecticides aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, and lindane; and the herbicides 2,4-D, 2,4,5-T, and Silvex. Each pesticide was detected at one time or another; and every stream sampled contained pesticides at least one time. DDT was the most frequently occurring insecticide, and 2,4-D the most common herbicide. The amounts observed were small; the maximum concentration of DDT was 0.12 µg/l and of 2,4-D, 0.35 µg/l. Concentrations were highest in the water samples that contained appreciable amounts of suspended sediment.

Pesticides in Florida

More than 50 million pounds of chlorinated hydrocarbon, organophosphate, and carbamate pesticides are used annually in Florida. Residuals from these compounds exist in various parts of the environment. M. C. Kolpinski and A. L. Higer report that an average of 0.02 µg/l of the DDT family (total of DDT, DDD, and DDE) was found dissolved in the surface waters of Everglades National Park. In addition, samples from several aquatic plants and animals showed biological magnification of insecticides. Their tissues contained more than 1,000 times the amount of the DDT family found in the waters.

Biological effects on water quality

The effect of environment on nutrient dynamics in microcosms is being studied by G. G. Ehrlich under controlled conditions in the laboratory. Treated sewage effluent in which all the soluble nitrogen was in a reduced form, predominantly as ammonium ion was exposed to different conditions of light and of aeration. Lighted aerobic cultures in bottles exhibited a rapid decline in the total soluble nitrogen, phosphate, and silica concentrations with the formation of a luxuriant algal growth after 7 days. Darkened aerobic cultures exhibited nitrification during which reduced nitrogen species were quantitatively converted to soluble nitrate with an intermediate buildup of nitrite. There were virtually no changes in the total soluble nitrogen, phosphate, or silica concentrations in the darkened aerobic cultures.

By contrast, lighted but tightly closed bottles simulating anaerobic conditions exhibited a slow decrease in the total soluble nitrogen, phosphate, and silica concentrations with development of algae. Nitrate and ni-
Chloride contamination in Caloosahatchee River, Fla.

D. H. Boggess found that the Caloosahatchee River upstream from the W. P. Franklin Dam was contaminated by salt water throughout a 12.5-mile reach in 1968. Most of the contamination resulted from repeated injections of salt water through the boat locks at the dam during the low-flow period. The higher density salt water occupied the deeper parts of the river channel, generally at depths greater than 12 feet. The maximum observed chloride concentrations were 3,580 mg/l near the bottom of the channel and 370 mg/l at the surface. The chloride content of the water in both the deep and shallow zones decreased with increased distance from the dam.

Neutralization of acid mine drainage in western Kentucky

In the Tradewater River basin near Clay, Ky., Craborchard Creek drains an area that has been largely strip mined for coal. H. F. Grubb and P. D. Ryder found that in July 1968, Craborchard Creek had a high specific conductance (2,400 \( \mu \text{mhos} \)), but a near-neutral pH of 6.5. All water entering Craborchard Creek above Clay flowed from strip-mined areas and had an average pH of about 3.1, with the exception of one tributary draining a large strip-mine lake. The pH of this tributary was 7.2 and is believed to be influenced by calcareous shale in the spoil material and bedrock near the lake. The flow from this tributary neutralized the acid water in Craborchard Creek and caused the near-neutral pH observed at Clay.

Brine contamination in southwestern Arkansas

A study by A. H. Ludwig of the alluvial aquifer in a 25-sq-mi area near Garland City, Ark., shows that the chloride concentration exceeds 250 mg/l in about 10 percent (60 million gallons) of the water. This high chloride content has seriously damaged irrigated crops in the area. The maximum observed chloride concentration was 46,000 mg/l. The natural chloride concentration in the alluvium and in the fresh water-bearing formations beneath the alluvium generally is less than 100 mg/l.

Water budget of Lake Sallie in western Minnesota

As part of a Federal Water Pollution Control Administration research project on accelerated eutrophication, the water budget for Lake Sallie is being determined by W. B. Mann IV and T. C. Winter. The study includes the inflow-outflow relationships through a chain of lakes, including Lake Sallie, on the Pelican River. As the calcium bicarbonate type water passed through the chain of lakes, the dissolved-solids content decreased from about 350 mg/l to 220 mg/l, calcium de-
creased from about 70 to 25 mg/l, and total phosphates decreased slightly from 0.36 to 0.25 mg/l. The groundwater flow pattern in the vicinity is being defined by observations at 29 locations, and test drilling has disclosed a relatively impermeable till which probably underlies Lake Sallie at depths of 5 to 40 feet.

**Rate of exchange and cation exchange capacity of stream sediment**

A potassium specific-ion electrode has been used by R. L. Malcolm and V. C. Kennedy to determine the rate of barium-potassium exchange and cation exchange capacity (CEC) of size-fractionated stream sediment. A series of sequential exchange rates were established ranging from very rapid (75 percent exchange occurring within 3 seconds on clay fractions) to very slow (75 percent exchange requiring 12 hours on gravel fractions). The average CEC of the clay, silt, sand, and gravel fractions was 37.6, 11.0, 9.7, and 7.2 meq/100 g, respectively.

The CEC of the sand and gravel mineral fractions was appreciable at 6–7 meq/100 g. Because of the high CEC of these fractions, they must be included in the total exchange, chemical properties, and transport phenomenon of the stream. It is believed that the CEC of sand and gravel fractions of soils and sediments have been underestimated in the past because the methods of CEC determination do not provide adequate times of saturation and exchange on these size fractions.

**DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH**

**Symposium on environmental geochemistry**

Representatives of the U.S. Geological Survey met several times during the past year with representatives from universities and other government agencies to plan work groups and projects that might facilitate an exchange of information regarding possible effects of trace elements in the physical environment on geographic patterns of disease in humans. The exchange of information among research workers in the fields of geochemistry, agriculture, and medicine is especially needed. As a result of these meetings, a symposium, "Environmental Geochemistry in Relation to Human Health and Disease," sponsored by the Geological Society of America, was held at the annual meeting of the American Association for the Advancement of Science (AAAS) in Dallas, Tex., December 30, 1968. The symposium was planned and led by H. L. Cannon (U.S. Geological Survey) and H. C. Hopps (Armed Forces Institute of Pathology). Five members of the Geological Survey contributed to the symposium. H. A. Tourtelot discussed the variations in the chemical composition of rocks, which may permit the recognition of geochemical provinces characterized by deficiency or excess of certain chemical components. M. W. Skougstad described variations in chemical composition of water that may result from differences in geologic source, seasons, and the treatment of water. In a panel discussion on problems in assessing the geochemical environment, F. N. Ward discussed problems of precision and reliability in chemical analysis, and A. T. Miesch discussed experimental design in both sampling and analysis. H. L. Cannon discussed the geologist's involvement in the pollution problem and the importance of geochemistry in environmental studies. The papers discussed above, and other papers contributed by research workers in medicine and agriculture, are being processed for publication in the memoir series of the Geological Society of America.

**Zinc in peat soils**

H. L. Cannon and R. R. Tidball studied the changes in zinc content of peat soils and vegetation growing on the soils brought about by drainage of what was formerly a peat bog near Manning, N.Y. The bog was drained in 1935 and has since been under cultivation for root vegetables. Sampling and analysis of the soils and plants in 1946 and again in 1967 have shown that the median total zinc content of the soils (on a dry-weight basis) decreased from 26,000 ppm to 2,800 ppm. Similarly, the median zinc content of the ash of native plants decreased from 19,000 to 3,000 ppm. Drainage of the area is thought to have resulted in oxidation of the zinc and removal in ground water.

Local areas of the former bog, however, have remained agriculturally unproductive, and attention is now being given to possible toxic effects of other elements. The median lead content of the soils decreased from 110 ppm in 1946 to 23 ppm in 1967, and a corresponding reduction was observed in the lead content of plant ashes—107 to 20 ppm. Although cadmium was not determined in samples from the earlier collection, its concentration in both soils and native-plant ashes from the collection in 1967 is 2.5 ppm. Values as high as 105 ppm were obtained in some soil samples and may approach the tolerance limits of the vegetation.

**Environmental geochemistry study in Georgia**

In a cooperative study with the U.S. Public Health Service, H. T. Shacklette investigated the concentrations of elements in soils and plants from two areas of Georgia that have greatly contrasting mortality rates for cardiovascular (heart and blood vessel) disease. Analyses of uncultivated soils and garden soils from the two areas indicated that samples from counties...
with low mortality rates in northern Georgia contain significantly higher concentrations of most major and trace elements that were studied than are contained in samples from counties with higher mortality rates in central and southern Georgia. Analyses of samples of native trees indicated trends in element concentration similar to those of soils from the two areas; samples of garden vegetables, however, were found to be much less sensitive to variation in the chemical composition of soils. If the hypothesis is accepted that cardiovascular mortality rates and geoclimatic characteristics in Georgia are causally related, the cause of the diseases would seem to be a deficiency, rather than an excess, of certain elements in the environments of the highdeath-rate area.

**LAND SUBSIDENCE**

Studies of land subsidence caused by the extensive pumping of ground water are continuing in a number of States and abroad, and are contributing to the knowledge of the hydrologic characteristics of compressible systems. Twenty-seven abstracts were recently submitted by United States authors for the forthcoming International Symposium on Land Subsidence scheduled for Tokyo, Japan, in September 1969. Of this group, 13 were U.S. Geological Survey employees.

**Subsidence in southeastern Texas**

Interpretation of records of a 760-foot compaction recorder at the NASA (National Aeronautics and Space Administration) site, 20 miles southeast of Houston, Tex., by R. H. Gabrysch indicates that all subsidence is due to compaction of fine-grained water-bearing deposits above the 760-foot depth. This is in contrast to the Houston area where most of the compaction is in older, deeper deposits. It is significant that interfingered silt and clay layers at depths below 760 feet at the NASA site are not compaction appreciably even though water levels are declining in these deeper zones.

Bench marks in the Orange County area along the border with Louisiana are being releveled by the Topographic Division of the U.S. Geological Survey. This area was last leveled in 1954, and early data suggest that significant subsidence has occurred during the intervening 15 years.

**Subsidence produced by ground-water pumpage at Baton Rouge, La.**

Studies in the Baton Rouge area indicate that as much as 30 cm of land subsidence occurred during the period 1900-65. G. H. Davis and J. R. Rollo compared the leveling data with those of distribution of ground-water pumpage and decline in head, and they conclude that subsidence is due mainly to cline in artesian head. Maximum subsidence is centered in the heavily pumped Baton Rouge industrial district. Lines of equal subsidence drawn for the period 1934-65 show a bowl-shaped depression slightly elongated east to west; the 5-cm subsidence line enclosed an area of 200 sq mi.

Average head decline in the area of maximum land-surface change has been about 200 feet since pumping of confined water began about 1890. This suggests a ratio of subsidence to head decline of about 0.5 foot of subsidence for each 100 feet of head decline. Although subsidence to date has been relatively small, it can be expected to continue with continuing head decline.

**Land subsidence in Alabama**

Land subsidence in Columbiana, Shelby County, Ala., during September 1968 damaged several buildings, water lines, railroad tracks, the municipal water filter plant, and endangered elevated storage tanks. Columbiana is underlain by a network of solutionally enlarged openings in limestone. As a result of the subsidence, two wells used as a source of municipal water supply in Columbiana were abandoned and two new wells were constructed approximately 8 miles southeast of Columbiana.

A reconnaissance study of the area by W. J. Powell (U.S. Geological Survey) and P. E. LaMoreux (Alabama State Geologist) indicated that the subsidence was caused by a substantial lowering of the water table due to pumpage and drought conditions.

**Earth fissuring in the San Joaquin Valley subsidence area, California**

A large earth fissure, half a mile long and as much as 8 feet wide, developed in March 1969 on the perimeter of the Pixley subsidence cone on the east side of the San Joaquin Valley, Calif. B. E. Lofgren reports that even though surface flooding triggered the opening of the fissure, the cause of the fissuring is probably related to stresses surrounding the subsidence cone and probably to stratigraphic and structural anomalies in the immediate area. A detailed study of the Pixley fissure and reported earlier fissuring 15 miles to the south is in progress.

**Subsidence related to pumpage in the Bakersfield area, California**

Ground-water pumpage, based on power computations, has recently become available for the subsidence area south of Bakersfield. An interesting relationship between areal pumpage and volume of subsidence has been found by B. E. Lofgren, which provides a useful
LAND SUBSIDENCE

Parameter of the recharge characteristics of the area. This relationship is of special interest to local water agencies importing surface water to alleviate subsidence.

Elastic response of aquifer system in Santa Clara Valley, Calif.

In the spring of 1968, the artesian head at a well field in central San Jose recovered 30 feet above the 1967 high and caused a net expansion of the confined aquifer system for the first time since compaction recorders were installed in 1960. J. F. Poland reports that a stress-strain plot of artesian head versus compaction indicates that system response was entirely elastic for head fluctuations in the 160 to 190-foot depth range. The slope of the elastic response line indicates that the component of the storage coefficient attributable to elastic response of the confined aquifer system skeleton 200 to 1,000 feet below the land surface is $1.25 \times 10^{-3}$.

F. S. Riley reports that the compaction recorder near Agnew, 5.5 miles northwest of San Jose, has recorded measurable elastic expansion every year since its installation in 1968. In 1967 and 1968, most observed deformation was within the elastic range. Maximum compaction during these years was 0.11 and 0.13 foot, respectively. However, net compaction during both years was only 0.02 foot. A stress-strain plot shows that during these years permanent plastic compaction occurred only when artesian head declined below about 130 feet. The slope of the stress-strain curves defines the component of the artesian storage coefficient due to aquifer-system elasticity as $1.5 \times 10^{-3}$. Specific storage due to aquifer-system elasticity is $6.5 \times 10^{-6}$ ft$^{-1}$.

Computer program available for relating compaction to water-level changes

After more than a year of experimentation, a computer program is now available for graphic plotting of digitized water-level and compaction data and relating these in a stress-strain relationship. This is a versatile program according to B. E. Lofgren, adapted to complex aquifer systems of multiple water levels and several compacting intervals. Most of the field data from the California subsidence areas will soon be on computer cards, and much of the tedious hand plotting of graphs and manual computations of data are being replaced by the computer.
Regional lunar geologic mapping

A geologic map of the lunar nearside at a scale of 1:5,000,000 is being prepared by D. E. Wilhelms and J. F. McCauley. The map will use the Aeronautical Chart and Information Center LEM-1 photographic mosaic as a base, and will cover the same area as the forty four 1:1,000,000-scale geologic quadrangles.

During the past year, progress was made toward publication of 1:1,000,000-scale geologic maps of all the quadrangles of the lunar nearside hemisphere. Three maps were published (Theophilus, Mare Vaporum, Ptolemaeus) in the central part of the equatorial belt, bringing the total number of quadrangles published since the program began to 16 (fig. 5). Maps of two quadrangles (Sinus Iridum and J. Herschel) outside this belt were completed, and others are advancing toward publication.

Possible volcanic materials on the lunar terrae

Studies by D. E. Wilhelms of Lunar Orbiter F r photographs showed materials of probable volcanic origin to be more extensive and varied in the terrae than...
had been recognized by telescopic observations. Positive landforms of probable volcanic origin include small smooth clustered domes and large rough convex domes. Most of these landforms were previously considered to be structural features modified by erosion. Probable volcanic craters include (1) rimmed and rimless craters of irregular outline, (2) smooth-rimmed round craters, (3) craters in chains and clusters, (4) irregular rings, and (5) distinctive widened furrows. Many of these were previously considered deformed, eroded, or coalescent impact craters. The domes and craters described are commonly superposed on probable impact craters, suggesting that the present overall form of many craters is a hybrid produced by both impact and volcanism. Although several independent lines of evidence indicate that the terra materials are generally older than those of the maria, many terra deposits blanket fairly young craters, suggesting that in some places, volcanic activity is nearly as recent as in the maria. Terra domes are generally steeper and higher than mare domes, and most terra materials have higher albedo than mare materials, suggesting a compositional difference.

Slope-stability studies

The influence of seismic activity on the stability of lunar slopes was investigated by G. L. Martin, and a method of indirectly evaluating lunar bearing capacities was developed. Methods of slope stability analysis that could be used in the indirect evaluation were reviewed, and stability charts, based on the "method of slices," were developed with the inclusion of horizontal seismic acceleration as one of the variables.

These studies showed that the effects of seismic activity on the lunar surface should not be ignored when using slope-stability techniques to evaluate lunar bearing capacity. Available data indicate that the static mass bearing capacity on the lunar surface should be at least 225 g/cm², and the upper limit could be as high as 4,000 g/cm² for footings 1 m across.

Bearing-capacity estimates from boulder tracks

Estimates of static bearing capacities by H. J. Moore using boulders at the end of boulder tracks shown in Lunar Orbiter II photographs yielded values between 0.5 and 9.3 newtons/cm² for blocks between 1.4 and 8.5 m across. Friction angles ranging from 10° to 30° were computed using Terzaghi’s bearing-capacity equation for circular footings, a cohesion of 10⁵ dynes/cm², a lunar γₗ of 220 g/cm²sec², dimensionless numbers for general shear, and measured footing radii and depths. These values are less than those reported using data collected by Surveyor spacecraft. However, the friction angle of one boulder shown in Lunar Orbiter V photograph H95 was computed to be 30° to 35°, in approximate agreement with Surveyor results.

Astronomical infrared studies

Using a previously designed photometer, an infrared mapping study of Jupiter was completed by R. L. Wildey. Six brightness temperature maps resulted. A significant variability in the correlation of thermal and reflected image structure was found, together with evidence strongly suggesting that the Jovian atmosphere stores energy at a rate often very large compared to the rate at which energy is radiated.

Automated data-handling system

A computer system for information storage and compilation has been written by D. H. Dahlem and J. B. Fife that will store the data of oral geologic descriptions, make available such information for instant retrieval, and display it in a data support facility on either a printer or plotter. The recording format is transparent to information structure and does not impose any arbitrary data structure on the incoming information. Data are recorded in an abbreviated form because of computer-storage limitations. Current efficiencies in storage make the use of full English language terminology practical. A parser is currently being developed.

CRATER INVESTIGATIONS

Sierra Madera structure, Texas

Mapping of the Sierra Madera structure, a circular zone 71/2 miles across of deformed Permian and Cretaceous rocks at the southern edge of the Delaware basin in west Texas, was completed by H. G. Wilshire, T. W. Offield, David Cummings, and K. A. Howard. Inward from a belt of concentrically faulted and brecciated rock marking the outer limit of the structure is a ring-shaped depression that encloses a marked central uplift. High structural relief and intense folding, faulting, and brecciation are evident at the surface, but drill holes show they die out at a depth of 6,000 to 8,000 feet. Individual minerals, especially in breccias of mixed lithologies in the central uplift, show extensive damage of a type known primarily in naturally and artificially shocked materials. The location of Sierra Madera is a broad area of otherwise mildly deformed rocks, its lack of relationship to regional structure, its detailed and overall geometry, and many signs of shock deformation suggest that it is the eroded root
of an impact crater that was between 3 and 8 miles in diameter.

Decaturville structure, Missouri

Preliminary work by T. W. Offield and H. A. Pohn showed the Decaturville cryptexplosion structure to consist of a central dome surrounded by a structurally depressed ring zone. Strata of the ring zone commonly are downfaulted more than 200 feet along a fault which appears to delimit the entire structure. Shatter cones are well developed but do not occur beyond 1,500 feet from the center of the structure. On the basis of abundant subsurface information provided by the Missouri Geological Survey; structure-contour and isopach maps were made for a large area around the structure; these show that three subsurface linear features intersect at Decaturville. Several new finds of fossils confirm that the structure is post-Silurian in age and add to knowledge of Paleozoic geography of central Missouri.

Gosses Bluff astrobleme, Australia

D. J. Milton, working on a joint U.S. Geological Survey–Bureau of Mineral Resources of Australia geologic and geophysical study of the Gosses Bluff astrobleme, Northern Territory, Australia, measured striations of shatter cones in the central uplift and surrounding disturbed zone. Computer analysis shows that striation vectors at 83 localities define good complete cones, even though apparently diverse segments rather than complete individual cones are the rule and some segments belong to the negative branch of the cone. Apical angles range from 66° to 96° with a mean of 80.5°. Mean apical angles decrease slightly from 83° in the lowest strata to 78° in the highest. The angle between bedding and the upward-pointing cone axes decreases from more than 80° near the center to 5° at a distance of 41½ km. If beds are restored to horizontal at elevations appropriate to the stratigraphic position (but ignoring the inward translation during central uplift indicated structurally), axes point to a focal zone above the center of Gosses Bluff within which foci of cones from successively higher strata lie above one another through an interval of about 1,700 m with its top near the estimated pre-impact ground surface. The vertical spread may reflect greater inward translation of the rock from the deeper strata now exposed nearer the center. Alternatively, the shock front (assumed normal to the cone axes) may not have propagated as an expanding hemisphere. Differences of cone orientation between nearby localities indicate that at least locally the hypothesis, that cones form normal to a smoothly advancing shock front, cannot be strictly maintained.

Two newly discovered possible astroblemes in Australia

Two previously undescribed circular structures of probable impact origin were discovered by D. J. Guppy (Bureau of Mineral Resources, Australia) and Rob in Brett in the Northern Territory. The first, the Liverpool Crater, is about 5 miles west of the Liverpool River, and approximately 35 miles upstream from its mouth in Boucau Bay, Arnhem Land. The second, the Mataranka Crater is approximately 45 miles southwest of Elsey Station, near Mataranka.

Mule Ear diatreme, Utah

Field mapping of the Mule Ear diatreme was completed, and the geology is being compiled by D. E. Stuart-Alexander. The diatreme is a kidney-shaped mass with a wide outer zone of predominantly down-dropped sedimentary blocks, an irregular middle zone of dikes of reconstituted sedimentary materials, and an elongate core of intrusive materials and upthrown xenoliths displaced upward from their original positions. At the present level of exposure, the core appears to be a series of pipes which are undoubtedly connected at depth and may have been connected above.

Simulated moon crater field, Cinder Lake, Ariz.

Two artificially created crater fields in Cinder Lake near Flagstaff, Ariz., were constructed for experimental purposes, including tests of tools and procedures that will be used in manned investigations on the Moon (see N. G. Bailey, G. W. Cotton, and Ivo Lucchitta, f. D172–D179). The crater fields are 1:1 scale replicas of areas selected in preliminary landing site II–P–6 in Mare Tranquilitatis. Realism was enhanced by the lack of vegetation at Cinder Lake, as well as its flatness and monotonous cover of unconsolidated basaltic pyroclastic debris. Detonation of buried charges excavated 585 craters. The craters match the equivalent Moon craters in Orbiter II photographs in size and distribution.

Explosion craters, Canada

A geologic study of the Prairie Flat crater was completed by D. J. Roddy as part of the tectonic analog comparisons with impact craters. Detonation of the 500-ton TNT surface sphere on alluvium by the Defence Research Establishment, Alberta, Canada, produced the Prairie Flat crater floor, a downfolded rim accompanied by high- and low-angle faults, a large overturned flap overlying the rim, and a continuous ejecta blanket. The crater is about 61 m in diameter and about 5 m in depth. The structural and topographic configuration is remarkably similar to certain large terrestrial craters of probable impact origin, such as
the Flynn Creek crater in Tennessee and the Steinheim crater in Germany.

Excavations of the rim of the crater were completed, and structural studies of the inner rim show that the original ground surface now dips 20° to 30° toward the crater. The ground surface in the inward-dipping rim has many low-angle thrust faults along which blocks moved as far as 2 m outward from the crater. Pervasive fracture systems concentrated under concentric ring folds beneath the crater floor allowed water to flow to the surface and localize sand cones that partly filled the crater floor.

A large overturned flap or foldback overlies the rim and contains continuous units of interbedded sand and clay lying in an inverted position. The foldback extends out as far as one crater diameter as a hummocky unit. Brittle fracture and radial separation of individual clay beds on top of the foldback produce narrow discontinuous concentric ridges that give a topographic effect similar to that seen around the young large lunar craters, such as Tycho.

Asymmetric extensions in the air shock wave and fireball, which occur as luminous jets and extensions, were produced by the detonation of the TNT. These have been correlated in position with asymmetric extensions in the crater ray ejecta pattern and foldback, and indicate initial inhomogeneities in the fireball and in the transmission of the shock wave to the ground. The inhomogeneities in the fireball are primarily responsible for the patterns of rays in the ejecta and of the distribution of the foldback.

**Thetomorphic ejecta from the Henbury craters**

Thetomorphic (shock metamorphosed) quartz and nickel-iron spherules have been reported by E. C. T. Chao and J. A. Boreman from shock ejecta from the Henbury craters of Central Australia. Detailed investigations of the thetomorphic quartz glass and quartz with low index (shock) lamellae show the possible occurrence of a high-pressure phase, coesite or stishovite.

**Investigation of feldspar glasses of greater-than-normal densities**

Thetomorphic (shock metamorphosed) feldspar glasses of densities greater than normal have been reported from shocked rocks by E. C. T. Chao (U.S. Geological Survey) and P. M. Bell (Carnegie Institution Geophysical Laboratory). In annealing and densification experiments, the objective has been to study the process by which dense glasses are formed and how this density changes as a function of temperature after pressure is released. The purpose then has been to slow down the various parts of the shock-wave process for careful observation by using static techniques. It is not possible to evaluate the actual rate process inasmuch as natural shock events probably last only a few microseconds to seconds and the actual characteristics of meteoritic impact ejecta are influenced by many factors. Some of these factors are the characteristics of the shock wave, the release adiabat, and the particle size.

These experiments show that glasses produced at high pressures will have a density consistent with the formation pressure. The high-pressure density will be lowered during annealing along uniform curves which depend on temperatures below the liquidus and will be increased at these temperatures if the pressure is raised.

**Shock effects in chain silicate minerals**

Samples from the Ries Basin, Germany, contain material suitable for study of the shock effects in chain silicates—minerals likely to be important in the returned lunar samples. Detailed studies by O. B. James and J. A. Minkin were begun on hornblende and augite, with emphasis on hornblende because it is far more abundant than augite in the samples.

The effects of shock in hornblende (as outlined by optical studies) are, with increasing shock pressure, as follows:

1. Broad smooth undulatory extinction and widely spaced deformation lamellae parallel to (101);
2. Mosaic undulatory extinction, in part related to cleavage and fracture, and fine lamellar twinning parallel to (101);
3. Mosaic undulatory extinction, fine lamellar twinning parallel to (101), and planar features (some are fractures, some are irregular planes of inclusions, and some are of undetermined nature) parallel to (100) and to planes in the zones (101) and (010);
4. Fragmentation of grains, strong mosaic extinction, and lamellar twinning and planar features as in (3);
5. Loss of green color and birefringence (grains are dusty pale brown), very fine mosaic extinction of some grains, abundant planar features on some grains, and banded extinction variation (possibly in part twinning) in some grains.

**COSMIC GEOCHEMISTRY AND PETROLOGY**

**Ultraclean laboratory**

An ultraclean laboratory for analysis of trace constituents in exotic samples was completed in Washington, D.C. The laboratory provides dust-free (fewer than 100 particles larger than 0.3 μm per cu ft of air) temperature- and humidity-controlled space, with provisions for chemical studies in laminar-flow ultraclean
fume hoods. Personnel enter the laboratory after donning nylon coveralls and passing through an air shower. Access is severely restricted in order to reduce contamination from outside the controlled environment facility. It is possible to set up experiments in which the contamination level is limited only by the ability to purify reagents and to clean laboratory ware. The laminar-flow design efficiently reduces the possibilities of contamination either by atmospheric dust or mixing of samples. With the improvement of analytical techniques to reach the part-per-billion range of many elements and isotopes and the advent of sensitive microconstituent analysis techniques such as the electron microprobe, it is expected that clean facilities will be required more frequently for geochemical analysis. M. B. Duke expects that his studies of the fine-grained portions and microconstituents of samples returned from the Moon will offer a means of thoroughly evaluating the capabilities of this laboratory for geochemical analysis.

New Chemical Data of Selected Australasian Tektites

Out of 112 high-precision chemical analyses of tektites, 70 were selected from the Australasian strewn field for comparison with other tektites in the Australasian region. Each tektite was analyzed for 11 major oxides (SiO₂, Al₂O₃, Fe₂O₃, FeO, MgO, CaO, Na₂O, K₂O, TiO₂, P₂O₅, and MnO) and 21 minor elements (Pb, Ag, Cu, Ca, Cs, Rb, Li, Mn, Cr, Co, Ni, Ba, Sr, V, Be, Nb, Sc, La, Y, and Zr). The analyses were made by Frank Cuttitta, M. K. Carron and C. S. Ansell. The chemical data are being reduced and analyzed statistically by A. T. Miesch and J. J. Connor, and will be interpreted by E. C. T. Chao and these contributors. Among the samples analyzed, 8 javanites and 2 australites of high specific gravity were submitted for analysis by Dean Chapman (National Aeronautics and Space Administration).

The 70 new analyses show that among the Australasian tektites, various chemical groups can be distinguished, as shown in the following tabulation:

<table>
<thead>
<tr>
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<td>Indochinites (18)</td>
<td>2.89–4.24</td>
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<td></td>
<td></td>
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<td>A</td>
<td>3.87–5.24</td>
<td>3.03–4.03</td>
</tr>
<tr>
<td>B</td>
<td>4.05–4.56</td>
<td>3.56–5.81</td>
</tr>
<tr>
<td>Australites (8):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1.72–2.40</td>
<td>2.87–4.05</td>
</tr>
<tr>
<td>B</td>
<td>2.32–2.72</td>
<td>2.58–2.81</td>
</tr>
<tr>
<td>C</td>
<td>5.99–6.71</td>
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The selected Thailand tektites with 71.1 to 74.7 wt percent SiO₂ are characterized by nearly equal low amounts of MgO and CaO. The analyzed indochinites having 72.3 to 76.5 wt percent SiO₂ are characterized by greater MgO than CaO. Most of the selected philippinates with 69.1 to 74.2 wt percent SiO₂ are characterized by greater CaO than MgO. One philippinite has high CaO content in excess of 4 wt percent. The javanites with 64.5 to 74.4 wt percent SiO₂ are higher in MgO than CaO; one group is low in MgO (2.88–3.73 wt percent) and high in K₂O (2.17–2.29 wt percent), whereas another group is high in MgO (3.61–7.95 wt percent) and low in K₂O (1.34–2.10 wt percent). Among the few australites analyzed (63.0–78.0 wt percent SiO₂) one group is low in CaO and MgO, particularly low in MgO; one group is high in CaO (in excess of 4 wt percent); and a third group is high in both MgO and CaO. One australite analyzed contains 3.85 wt percent Na₂O, which is similar to the Ivory Coast tektites but unique for Australasian tektites. The parameter that varies the least among the Australasian tektites in the Na₂O to K₂O ratio (0.4–0.8). The high magnesian Australasian tektites are also characterized in general by high Ni, Co, and Cr.

No terrestrial rock was found that is similar to those Australasian tektites with high SiO₂, low alkalies (K₂O greater than Na₂O) and MgO greater than CaO. It is inconceivable that these tektites could have been derived from a terrestrial basalt or rock of basaltic parentage. Those Australasian tektites with CaO greater than MgO, however, are similar to a rare type of alkalial-calcic granites with low alkalies. Extensive volatilization alone cannot account for the observed chemical variation, particularly in those rocks that contain either high MgO or high CaO. Wherever they are originated, these various chemical groups represent a variety of rock types if not varieties of two major rock types.

Chemical Inhomogeneity in Individual Tektites

Controlled investigation of chemical inhomogeneities of individual tektites was carried out by E. C. T. Chao, G. A. Desborough and E. J. Dwornik. The investigation employed the combined use of interference microscopy and electron microprobe analysis. The method is far superior to any previously tried method of separation and analysis of the separated portions of an individual tektite.

A detailed quantitative survey of the index of refraction of any point of interest of a tektite wafer can be determined by interference microscopy. The wafer is cut normal to the schlieren with plane parallel polished surfaces, and its thickness precisely measured. Areas of continuous and discontinuous index variation are clearly revealed. Areas of contrasting index of refraction are distinguished, as shown in the following tabulation:

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fraction or of maximum difference can be pinpointed for analysis by the electron microprobe.

Low-index glass inclusions and high-index glass inclusions have been studied by this combined method. In addition, investigation of the heterogeneous chunky Thailand tektites known as the Muong Nong type show that light-colored bands containing abundant frothy lechatelierite inclusions are actually higher in index than the adjacent more brownish glass that has fewer inclusions. In sharp contrast to the bulk composition, the chemical variation is complex and cannot be predicted on the basis of the index of refraction.

A low-index glass inclusion \((n=1.4994)\) in a Thailand tektite contains more \(\text{SiO}_2\) by 3.3 wt percent and less \(\text{Al}_2\text{O}_3\), total iron, \(\text{MgO}\), and \(\text{CaO}\) than matrix glass on either side \((n=1.5090\text{ and }1.5059)\) as determined by electron microprobe analysis.

Electron microprobe analysis of several recently discovered high-index glass inclusions in a javanite shows that the high-index glass inclusions are lower in \(\text{SiO}_2\) content than the matrix glass by 2.1 to 4.0 wt percent, higher in total iron by 2.1 to 2.4 wt percent, and higher in \(\text{MgO}\) by 2.4 to 2.7 wt percent. The fact that the inclusion contains as much as 8.7 wt percent \(\text{MgO}\) and 63.3 percent \(\text{SiO}_2\) but has \(\text{K}_2\text{O}\) (12 percent) greater than \(\text{Na}_2\text{O}\) (0.5 percent) and a high \(\text{Al}_2\text{O}_3\) content (11.4 percent) is unique. These high-index inclusions contain the highest amount of \(\text{MgO}\) and total iron among all land tektites investigated. Such inclusions help to bridge the gap in chemical composition of the land tektites and the deep sea microtektites.

The low-index and the high-index inclusions probably represent fused parent rock types. Such chemical variation represents a well defined range of chemical types of source material. On the basis of their mode of occurrence, it was concluded that these inclusions are not results of change by volatilization. Such inclusions more likely are evidence of incorporation of one rock type captured by another during the fusion and ejection process, and were not fused in place. The heterogeneity represented by lenticular banding or layering is evidence of inhomogeneity in the starting material.

It seems evident that controlled investigation of the chemical heterogeneity is a basic requirement for the interpretation and understanding of tektite genesis. The discovery of high-index inclusions in javanites strengthens the interpretation that the parent material of the basic end member of the magnesian clan of Australasian tektites is characterized by low alkalies, high \(\text{MgO}\) and \(\text{Al}_2\text{O}_3\) and moderate to low \(\text{SiO}_2\). If tektites are of lunar origin, such materials should be found among the returned lunar samples. The same prediction applies to the high-calcium types found at Santa Mesa in the Manila area of the Philippines. The composition of the end member of the calcium-rich clan is not inconsistent with the Alpha backscattering data of Surveyors V, VI, and VII.

**New chemical methods applied to the study of materials of astrogeologic interest**

A combined chemical X-ray fluorescence method was described by H. J. Rose, Jr. and Frank Cuttitta for determining rare-earth elements in small amounts of complex rare earth minerals and in materials of astrogeologic interest. These elements yield a complex X-ray spectrum in which many of the analytical emission \(\text{La}\) lines of a given element coincide with the \(\text{L}\) and \(\text{M}\) lines of a lighter rare-earth element several atomic numbers removed. The proposed analytical scheme corrects for these interferences. Sixteen elements consisting of the lanthanides, yttrium, and scandium can be determined on as little as a 1-mg portion of the separated oxides. The oxides are dissolved in 1 ml of dilute \(\text{HNO}_3\), absorbed onto cellulose powder, and pressed into a pellet for X-ray excitation. Chemically analyzed geologic standards are not required for calibration.

A neutron activation procedure suitable for the routine determination of tantalum and hafnium in silicates was described by L. P. Greenland. The irradiated sample is fused with sodium peroxide and leached, and the insoluble hydroxides are dissolved in dilute \(\text{HF}-\text{HCl}\). After \(\text{LaF}_3\) and \(\text{AgCl}\) scavenging, tantalum and hafnium are separated by anion exchange. Tantalum is obtained radiochemically pure; \(\text{Pa}^{233}\) and \(\text{Zr}^{95}\) contaminants in the hafnium fraction are resolved by gamma-ray spectrometry. The chemical yield of the procedure is determined after counting by re-irradiation. Values for eight U.S. Geological Survey standard rocks were reported.

A fast coincidence-counting technique was used by Greenland to simplify the determination of cobalt and cesium in silicate rocks and was applied to the same eight standard rock samples. After neutron irradiation, \(\text{Co}^{60}\) activity is counted directly in the sample with no chemical separations; \(\text{Cs}^{134}\) activity is counted after a rapid chemical separation from scandium.

**Achondrites and the Surveyor data**

M. B. Duke compared the chemical analyses obtained by Surveyors V, VI, and VII with data for eucrite and howardite achondrite meteorites, for which he has suggested a lunar origin. Data collected from mare sites by Surveyors V and VI closely resemble data for composition of eucrites, which is consistent with the model in which eucrites are derived from the maria.
The Surveyor VII analysis, of an atypical upland region, does not match well with the composition of the howardites, considered by the model to represent fragmental aggregates of upland rocks. However, the Surveyor VII analysis is consistent with the composition of rocks that can be inferred to be constituents of the howardites.

**Cosmic dust**

Debris believed to have been derived from the Revelstoke fireball of March 31, 1965, was collected on airborne filters flown approximately 3 days after the event at a considerable distance downwind from the path of the fireball. The filters studied by M. B. Duke and others contained an unusual assemblage of particulate materials, quite distinct from collections made under normal conditions. The most obviously anomalous characteristics is the large concentration of magnetic spherules, especially those less than 10μ in diameter. X-ray and microprobe analysis showed that the spherules consist of a very pure magnetite. Also present in comparable numbers are glass spherules composed largely of silicon and aluminum with lesser amounts of iron and potassium and trace amounts of nickel. In addition to the spherules are many irregularly shaped particles, mostly opaque and either glassy or microcrystalline. Approximately 20 percent of the opaque particles analyzed by the microprobe contain more than 10 percent nickel. In some, nickel was the only element detected; in others, only nickel and sulfur were detected or the particle appeared to be a mixture of nickel and silicate materials. Most of the particles are in the 10 to 20μ size range, making X-ray analysis marginal. Patterns have been obtained for some of the particles, but these have eluded interpretation.

The Revelstoke meteorite is a carbonaceous chondrite. The composition of the particles is difficult to reconcile with this type of meteorite. Revelstoke contains only minor amounts of nickel and aluminum, but the glass spherules are rich in aluminum, and many of the irregular particles are rich in nickel. The peculiar chemistry of the particles may result from selective ablation of different components of the meteorite during passage through the atmosphere.

Instrumental neutron activation analysis was used by H. T. Millard, Jr., to determine iridium in individual cosmic spherules separated from a marine sediment. The values found for the Ir/Fe ratio, 0.5 to 8 × 10⁻⁶, are in good agreement with the values for iron meteorites, which range from 0.3 to 15 × 10⁻⁶. These results tend to confirm the identification of cosmic spherules as ablation products of iron meteorites.

**SURVEYOR TELEVISION INVESTIGATIONS**

A preliminary analysis by E. M. Shoemaker and E. C. Morris of the pictures returned from the Moon by the five successful Surveyor spacecraft showed that at each of the Surveyor landing sites, the lunar surface is covered by a layer of fragmental debris including a variety of rock fragments. Some fragments are on the surface and others are partly embedded at various depths in a finer grained matrix. The fragments are scattered somewhat irregularly, and in most places sparsely, but strewn fields of blocks are found around some of the larger craters. Between 4 and 18 percent of the lunar surface is covered by fragments coarse enough to be resolved by the television camera (coarser then 1 mm). The Surveyor VII landing site has the largest number and variety of rock fragments, whereas the Surveyor V and VI sites have the least number of resolved rock fragments. Most resolvable fragments on the surface are significantly brighter, under all observed angles of illumination, than the unresolved fine-grained matrix. Most fragments appear to be dense, coherent...
rock, while some appear less dense and porous. Most fragments are relatively angular, but some well-rounded fragments are also present and appear to be fairly deeply embedded in the lunar surface material. On the whole, most fragments tend to be equant in shape, but some are distinctly tabular, and a few have the form of sharp, narrow wedges, some of which protrude from the surface like spikes.

Many blocks at the Surveyor VII site, and a few at the Surveyor I site, are distinctly vesicular. Spotted rocks, first observed at the Surveyor I site and also seen at the Surveyor V site, are common near Surveyor VII. Light spots on these rocks generally have indistinct boundaries and range in size from a few millimeters to several centimeters across. Much of the lighter material has slight bumps, or protrusions, on the surface of the fragments, suggesting that the lighter material is more resistant to erosion processes occurring on the Moon.

A knobby, pitted surface is the most common surface texture developed on the bright, coarse, rounded rock fragments. The pitted texture probably is produced by the same processes that produce rounding of the fragmental material on the lunar surface. The pits probably are produced by impact of small particles on the rocks. Further evidence that the surfaces of the rocky fragments have been subjected to an erosive, or abrative, action is evident on one of the rocks overturned by the surface sampler of Surveyor VII. This rock was rounded on the exposed side and angular on the subsurface side.

Some coarse fragments on the lunar surface are clearly aggregates of smaller particles. Some aggregates are compact and angular, whereas others appear to be porous and probably are only weakly compacted. Most of the small craters at each of the landing sites have a cup shape with walls and floors concave upward; most have low, subdued rims, but some are nearly rimless. Dimple-shaped craters lacking raised rims and crater chains are common at the Surveyor V site and were observed at the Surveyor III site. Dimple craters and crater chains are inferred to have been formed by drainage of the surficial fragmental debris into subsurface fissures. Most of the cup-shaped craters are probably of impact origin.

Many irregular craters, ranging in size from a few centimeters to several meters in diameter and lined with clods of fine-grained material, were observed at all landing sites. These are inferred to be secondary low-velocity impact craters formed by cohesive blocks or clods of weakly cohesive, fine-grained material ejected from nearby primary craters.

The preliminary analysis by H. E. Holt of the lunar pictures returned by the five landed Surveyor spacecraft showed that the fine-scale photometric properties of five widely separated lunar areas are similar. The general photometric properties of the uniform-appearing fine-grained surface material did not reveal any variations dependent upon lunar azimuth. The photometric function of the fine-grained material is symmetrical and very similar to the terrestrially measured lunar photometric function which was restricted to measurements in east-west phase planes (Earth-Moon-Sun plane). The Surveyor data also indicate that the lunar photometric function is virtually independent of scale down to resolutions of a centimeter, and small topographic irregularities appear to have negligible effect on the telescopically measured function. The albedo (normal reflectance) measurements of the undisturbed fine-grained material ranged from 7.3 to 8.5 percent on the maria sites and reached 13.4 percent in the lunar highlands near the crater Tycho. All disturbances of the fine-grained surface material exposed darker material, from 10 to 25 percent lower in albedo, at a depth of 1 mm or less. Smoothing of the fine-grained material by spacecraft footpads or surface sampler produced a more Lambertian reflectance without an increase in the estimated albedo. Thus, the peak backscattering nature of the lunar photometric function is probably due to multiple scattering from surfaces of very fine grains composing a very porous, low-density microstructure in the upper few hundred microns of the surface layer.

All coarse fragments and blocks protruding above the general level of the surface have noticeably higher reflectivity at low angles of solar illumination than the fine-grained material. The estimated albedo of the larger fragments ranged from 9 to 22 percent, and the photometric function more closely resembles a Lambertian scattering surface than does the function for fine-grained material. Most resolvable fragments appear to be dense coherent rock while others appear porous (vesiculated) or blocks and clods of weakly cohesive fine-grained material. Some larger fragments are clearly aggregates of smaller particles a few millimeters to several centimeters across. Rock surfaces at the Surveyor V and Surveyor VII landing sites showed small bright areas which varied in position as a function of illumination angle, and they probably represent specular reflections from glossy or crystalline constituents of the rocks. Most rock surfaces are dust free, although some rocks contained irregular surfaces or pockets where dust has accumulated.

Spectral measurements by J. I. Rennilson (Jet Pro-
pulsion Laboratory) of sunlight reflected from the lunar surface revealed no significant color differences among the various surficial materials. Lunar materials all appear light to dark gray as they are practically neutral reflectors.

Preliminary reduction of the polarization measurements by H. E. Holt from Surveyors VI and VII pictures indicate that the polarimetric functions of the fine-grained regoliths range from a maximum of 7 to 9 percent in the highlands to 16 to 19 percent on the maria. The degree of polarization was found to depend principally on the phase angle of the observation. The fine-grained lunar polarization function closely matches the polarization function of basalt and gabbro powders. The maria polarization function more closely matches that of basalt powders where the largest fragments are 75μ across, whereas the highland function is similar to basalt powders ground to 30μ and smaller in diameter.

Pictures taken with Surveyor cameras, from approximately the height of a man's eye, present unique problems in the cartographic portrayal of significant geologic details according to R. M. Batson. Large-scale maps, improved mosaics with superimposed perspective grids, and physical models have been prepared. Large-scale (1.1 to 1.5) physical models made from topographic data in Surveyor-type television pictures aid in scientific interpretation of lunar landing sites because the investigator is able to view the surface from all angles and under any illumination. The pictures and their associated telemetry data require extensive interpretation to determine significant spatial relationships, but these become obvious on a physical model.
REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SATELLITE (EROS) PROGRAM

EROS (Earth Resources Observation Satellite) is a Department of the Interior program to utilize remote sensor data acquired from aircraft and spacecraft for application to land use and resources investigations. The program is a cooperative one among several bureaus in Interior and involves collaboration with the National Aeronautics and Space Administration (NASA), Department of Agriculture, Naval Oceanographic Office, and numerous other Government and academic organizations. The EROS Program includes continuing research for the purpose of providing new or improved sensors and techniques that will result in better data and more effective use of the data.

The EROS/ERTS Programs will provide new kinds of data with significant potential value for Federal and non-Federal use in dealing with natural resource and agricultural problems, and understanding the interaction between man and his changing environment. Specific expected uses include detecting forest and crop diseases, inventorying crops, locating fish schools, surveying range conditions, mapping land use for urban planning, studying erosion and change along coastlines and major streams, and inventorying land use and landforms of the entire United States. EROS multispectral sensing will permit use of newly developing automatic techniques for identifying and measuring desired information contained in photographic images.

Performance specifications for space data were generated in 1966 under the EROS Program. These specifications have been incorporated into the initial design of NASA's Earth Resources Technology Satellite (ERTS) which is expected to be launched in late 1971.

The ERTS satellite will be in a polar, sun-synchronous orbit so that each point on the earth's surface will be sensed repetitively (every 17–20 days) at the same time of day. Each image will be virtually orthographic, covering a square area of 100 miles on each side. Approximately 2,500 images will cover the entire United States. It is expected that the data can be used for thematic maps at a scale of 1:250,000 or 1 inch equals 4 miles.

The initial satellite's prime remote-sensing devices will be multispectral vidicon cameras for three wave bands (475–575 m\(\mu\) or blue-green, 580–680 m\(\mu\) or red, and 690–830 m\(\mu\) or near infrared). The satellite may also include an optical mechanical scanning system, providing four bands of information in the visible and near-infrared part of the spectrum, and capability for relaying data from ground sensors (such as stream gages and tiltmeters) to the data center. The sensors will operate at command, collecting data only of the United States and of those countries requesting data.

The satellite will relay the collected data in electronic form through receiver stations on earth to a central processing center. At the center, this signal will be converted to photographic-type images for distribution to both non-Federal and Federal users and for storage for later reference. It is expected the system will handle an annual input of 48,000 images of the United States and disseminate over one million copies.

During the year the EROS Program continued on its mission of defining the applications of satellite data and developing satellite systems for earth resource mapping and management purposes. Research studies aimed at determining the feasibility of using multispectral photography and other remote sensor data from space were developed within several Interior bureaus and are now underway. A special multispectral photographic experiment (S065) was flown by NASA in the Apollo 9 space mission to provide user agencies and the scientific community with prototype data for earth resource information. Investigations of other remote sensor systems such as imaging radar, thermal infrared imagery, and microwave systems continued under applications programs discussed in this section of this volume.

The EROS Program contracted the Radio Corporation of America to make a detailed study of user data requirements and handling methods. Special studies were conducted of the needs and applications of data by the Tennessee Valley Authority and the Desert Research Institute. These investigations were designed to define the data handling system that will be needed to gather, process, and distribute repetitive data from the unmanned Earth Resources Technology Satellite (ERTS) to be launched in 1971.

The U.S. Geological Survey identified a number of...
products that can be produced rapidly and inexpensively from ERS data and that can fill an international need. The Survey is focusing its data handling efforts and research on production of these products from ERS data. The five first selected are:

1. A millionth scale photoimage map series of large segments of the earth could be produced by the Geological Survey and other Federal agencies whose missions are involved, using methods now being developed by the research program.

   The only internationally accepted mapping program is the millionth-scale map series overseen by the United Nations. The photoimage maps could be a useful and necessary supplement to this series.

2. A map series (and statistical data) showing surface-water distribution over large areas of the earth could be produced.

   An inventory of lakes is being conducted by the International Hydrological Decade Program; this survey currently being undertaken by postcard inquiry, will yield useful data but will certainly fall short of a timely inventory. The ERS data would help to manage water resources and to evaluate drought conditions.

3. A map series showing the distribution of forage grasses would be welcomed by nations having a grazing economy and would be extremely useful in the management of national grazing lands. The maps could be produced by the Geological Survey, in cooperation with the Department of Agriculture, the Bureau of Land Management of the Department of the Interior, and other agencies of the U.S. Government or of other nations, as appropriate.

4. A land-use map series is probably the most needed of resources information. Research shows that generalized land-use maps can be made from ERS data. A generalized land-use map of the United States could be produced in 1 year at a cost of about $100,000, using ERS data, and would be invaluable in understanding the dynamics of the urban-rural interface. Other nations could likewise benefit both directly and indirectly. For example, malaria is most prevalent in recently cleared tropical areas; thus, such maps could help to anticipate this health hazard.

5. A review of the current inventory and classification of geologic hazards, principally volcanoes and earthquake-prone fault structures to ascertain the adequacy and completeness of current inventories and classifications and hopefully to improve them. And in a longer-range view, to improve the understanding of earthquake and volcanic processes. The Geological Survey could produce a tectonic and volcanologic map. In all probability, these maps could stimulate application of technology to reduction of loss from these phenomena.

Other similar objectives could also be identified and steps taken to facilitate their early evaluation through mapping. These might include:

1. Flood-plain analyses,
2. Coastal-zone evaluations,
3. Surveys of National parks and other recreational areas,
4. Analyses of land subsidence resulting from mining and other causes,
5. Sources and dissemination of pollutants,
6. Surveys of biological and ecological environments on land and in shallow waters, and
7. Irrigation systems analyses and management.

APPLICATIONS TO GEOLOGIC INVESTIGATIONS

Studies evaluating remote-sensor techniques and the potential applications of space data to geologic investigations continued in cooperation with the National Aeronautics and Space Administration (NASA). The program was aimed at: (1) a development of a better theoretical understanding of remote-sensor response to various properties of rock and to surface contaminants; (2) an empirical analysis of remote-sensor data and space photography; (3) an improvement of instrumentation, data handling, and interpretation techniques; and (4) an evaluation of the use and applications of satellite communication in the relay of data from ground-based instruments monitoring active volcanoes and earthquake regions.

Program definition

G. D. Robinson completed an analysis of the U.S. Geological Survey Geologic Division's remote-sensing program and recommended that the program (1) focus on understanding the fundamental physics and chemistry that govern the response of rocks to the various remote-sensor techniques and (2) concentrate on the unique capacities of orbiting satellites, namely synoptic views of large areas and repetitive observations. Synoptic views of large areas will enable geologists to study regional geologic features and their relationships on a continental or even worldwide basis. Repetitive observations will enable routine monitoring of landscape changes such as those caused by shoreline erosion and sedimentation, volcanic eruptions, and major earthquakes. Robinson also emphasized that remote sensing from aircraft has great scientific and economic potential for the geologic profession and suggests that these possibilities be explored more vigorously.
Fundamental studies

A detailed field observation program was conducted at four quartzose field areas (Mill Creek, Okla.; Grand Sable Dunes, Mich.; Beartooth Mountains, Mont.; and Baraboo, Wis.) to examine the “noise” characteristics of the atmosphere, grain size or rock texture, and surface contamination. A laboratory infrared spectrometer modified for field use and with a relatively long spectral scan time (approximately 15 minutes) was used by R. D. Watson to measure the perturbing effects on the diagnostic spectrum of quartz. Analysis indicates that time-varying atmospheric effects can completely mask any of the subtle features of the rock spectral emission. The effects of surface grain size were examined by Watson and P. J. Cannon in the quartz sand quarries at Mill Creek, Okla. The more recently worked quarries generally were coated with a very fine quartz powder which changed the structure of the characteristic reststrahlen peaks. Older quarries, where the fine powder was removed by erosion, showed the characteristic reststrahlen features. The effects of surface contamination on the quartz spectra, on the other hand, were variable: in some areas where lichen cover was significant, the diagnostic quartz spectrum was still clearly visible but in other areas lichen cover completely masked the quartz spectrum and the resulting signal resembled a black body. In addition, surface coatings were found to either completely eliminate the reststrahlen features or to produce a complex composite spectrum. A laboratory study by Watson of the infrared reflection spectrum of a pyrophyllite-coated quartz sample taken from the Baraboo field area demonstrated one type of composite spectrum that can be produced by surface coatings. It was found in this case that the composite spectrum, although much more complex than either the pure pyrophyllite of quartz spectrum, could be understood in terms of a simple mixing ratio of the two pure spectra. It is anticipated, however, that examples of composite spectra will be found that will indicate a complex interaction between coating and substrate such that a simple mixing law relationship will not be valid.

Preliminary measurements by Watson of the emission characteristics of atmospheric dust indicate that detection and identification of particulate matter are possible when significant concentrations are present. Measurements of dust clouds downwind of a dolomite processing plant at Mill Creek, Okla., show the presence of dolomite reststrahlen.

Field studies of the atmospheric emission spectra in the strong absorption regions (6.5, 9.3, and 14μ) and of the transmission spectra in the more transparent windows (between these bands) indicated very significant time-varying characteristics of the atmosphere. The present spectrometer which requires a scan time of 15 minutes to go from 7 to 14μ was unable to measure rock and soil emission spectra with a sufficient signal-to-noise ratio to observe subtle variations in the surface spectra during times when the atmosphere was “noisy.” These results indicate the importance both of having a precise atmospheric model (including its time-varying characteristics) for detailed interpretation of emission spectra and of reducing the scan time by at least an order of magnitude.

The applications of nonlinear least-squares estimation to dispersion analysis, a technique which compares theoretical models to observed data, provides a powerful tool to examine the influence of rock composition and texture on the physics of reflection and emission of electromagnetic energy. Initial application by Kenneth Watson of this digital computer technique in conjunction with computer-stored atmospheric models provided a basis for preliminary interpretation of field infrared spectra. Increasing the oscillator damping constant, which broadens the width and reduces the contrast of quartz at decreasing grain sizes.

Comparative analysis of remote sensor data

M. M. Clark studied high-altitude aircraft and space photography of active fault-zone regions in southern California and found that in many places, small-scale photographs offer the most reasonable way of detecting or projecting regional features that have interrupted expression at the surface. Large areas displayed in stereomodels of small-scale air photographs revealed regional relations not apparent on mosaics of the same scale or not apparent on stereomodels covering smaller areas. Where topography is important to geologic investigations, aerial photographs taken with low sun angle (10–30 degrees) are considerably more useful than the commonly available photographs taken at higher sun angles. Much of the geologic usefulness of side-looking radar images can be duplicated in small-scale, low sun-angle aerial photographs which have additional benefits not present on radar images.

An evaluation by R. J. Hackman and P. L. Williams of 3–5μ infrared line-scan (IR) imagery and color photographs covering parts of southern Utah shows that IR images and color photographs have some unique features. In general, the IR imagery provides a day or night record of relative ground temperatures for large areas of terrain. In sparsely vegetated areas, night IR
shows some tonal variations presumed to be temperature differences that may be related to differences in rock types. In heavily vegetated areas, any temperature difference that might exist between rock units is masked by the temperature difference associated with different vegetation communities; however, isolated outcrops in such areas are generally apparent because they are brighter (warmer) on the day IR. These outcrops may or may not be warmer on night IR, depending on their diurnal-absorption and subsequent nocturnal-radiation characteristics. Roads in heavily wooded areas are easier to see on the IR image than on conventional photographs because of their temperature contrast with adjacent terrain. Heat patterns resulting from modification of the land by man and from the effect of cloud shadows are also important in the analysis of IR images. Color photographs, as might be expected, show the terrain in a close approximation to its natural color, and thus aid in the delineation of some rock units and alteration zones that are indistinguishable on black and white photographs.

D. F. Crowder and M. F. Sheridan compared many true-color, infrared-color, and multispectral photographs of their study area near Bishop, Calif. True-color photographs were judged the most useful for studying the general geology. Geographic locations were easily recognized on these photos and though known contacts between rock formations were visible on most photos, they were generally most conspicuous on the true-color film. The infrared-color film showed certain contacts with particular clarity, but no overall advantage in general utility was evident. The enhancement of vegetation and the haze penetration characteristic of infrared-color photos are of no noticeable advantage in this barren desert where the air is relatively clear. In addition, those vegetation patterns that do exist do not seem to have any close relationship to the principal geologic features of this study area.

Infrared imagery (8–14 μm band) in the Pima copper district, Arizona, studied by J. R. Copper, shows that alluvium within areas of rapid excavation above the large Twin Buttes copper deposit are relatively warm (bright) on nighttime images. This anomaly seems adequately explained by the normal geothermal gradient. Thermochemical heat from oxidizing sulfide minerals may be a factor in the tonal expression of tailings ponds, leach dumps, and mineralized bedrock, but its effects are too subtle to be distinguished with assurance among the many other factors involved.

E. W. Wolfe completed studies of remote sensor data in the Caliente and Temblor Ranges and the Anza Borrego Desert of southern California. In the data from the Caliente and Temblor Ranges, he found that while outcrops of shale along Bitterwater Creek show high reflectance (bright) in black and white aerial photography, they emit very little thermal energy and are therefore relatively cool in predawn infrared imagery. Radar images show them as dark features compared to surrounding alluvium. This effect is believed to be due to fine grain size and relatively smooth surface of the shale in outcrop areas. The Santa Margarita Formation, on the other hand, consisting of sandstone and debris containing abundant metamorphic and granitic boulders, has a rough surface and, therefore, appears bright on radar images.

Wolfe also analyzed multispectral photography, infrared imagery and microwave data acquired by NASA and others over the Anza-Borrego Desert State Park west of the Salton Sea in southern California. He found that the spectral bands selected for the multispectral photography were too broad to define the differences in spectral character of the rock units. Studies of 8–14 μm infrared imagery indicated that thermal inertia, reflectivity and slope angle were important factors influencing nighttime imagery. Thermal inertia increases with increasing specific gravity or with moisture content. Porous weathered gyspum having low specific gravity, has low thermal inertia, and its surface cools rapidly at night. Granite, on the other hand, has higher specific gravity and a higher thermal inertia and, therefore, cools less rapidly at night. Certain areas that lack vegetation, appear to be more highly reflective on nighttime imagery than vegetated areas with similar rock. Slopes with angles of about 30° have more radiance than slopes of the same surface materials at 10° or less. These differences may be due to the possibility that nearly horizontal surfaces receive minimal radiation from the atmosphere or from other ground surfaces during the day. Microwave radiometer measurements, recorded at 9.2, 15.8, 22.2 and 34.0 GHz were obtained along two flight lines from an altitude of several thousand feet. L'ectinctive but inconsistent surface temperatures, apparently related to geologic features were found only at the 9.2 GHz frequency where lower temperatures were found associated with a belt of alternating mudstone and sandstone. The relationships of microwave data to major geologic features are not simple and warrant further investigation.

R. D. Brown, Jr., concluded studies of infrared imagery of the Parkfield-Cholame area, California, where earthquake-associated fractures exhibiting several inches of right-lateral strike slip displacement were formed during June through August 1966. The infrared imagery, obtained during July 1966, was acquired to determine whether detectable thermal anomalies,
marked by 8–13 μ infrared radiation, accompany active faulting. Although no anomalies of the type sought were detected, the imagery very clearly illustrated a number of features that helped locate the San Andreas fault, certain rock types, and other surface features. In places, vegetation patterns permitted local identification of the fault zone. Alluvium, crystalline rocks, and possibly late Tertiary and Quaternary nonmarine strata were identifiable and crudely mappable by their infrared patterns. Most of the characteristic patterns that distinguish different rock units in the infrared imagery are believed to be due in part to vegetation contrasts which are probably related to the physical and chemical properties of the soil and to its moisture content. Insofar as these properties reflect underlying bedrock character, the vegetation patterns can be successfully used for geologic interpretation.

S. J. Gawarecki completed analysis of 8–14 μ infrared imagery obtained over the Pisgah Crater area, San Bernardino County, Calif. The imagery, flown in February 1965 and August 1966, included six flights throughout a diurnal cycle and was aimed at defining the optimum observation times to permit distinction between a variety of rock types and surface materials. Representative thermal contrasts were obtained at the following times: 2000 (postsunset), 0400 (presunrise), and 1200 (midday). Best results were obtained from imagery flown after sunset. Geologic features best defined on the imagery of one or more flights included (1) basalt flow contacts where adjacent flows differed in surface character, (2) distribution of pyroclastics and their alluvial derivatives on the flows, (3) collapsed lava tubes, (4) fissured areas, (5) details of the Pisgah fault, (6) zonation within Lavic dry lake, (7) active drainage on an alluvial fan, and (8) moist areas suggestive of ground-water conditions.

R. B. Morrison completed compilation of a soils association map of the southwestern United States and northern Mexico, an area of nearly 150,000 square miles, from studies of Gemini color photography. A mosaic composed of rectified Gemini photographs, at a scale of 1:1,000,000 was used as the compilation base. Using the color of the surface soil and topographic-geomorphic features, Morrison was able to map five major soil groups and nineteen subgroups. Field checking and refinement of the map continued during the year in cooperation with the U.S. Soil Conservation Service and specialists of the Mexican Government.

**APPLICATIONS TO GEOLOGIC INVESTIGATIONS**

**Line-scan infrared imagery of Iceland’s neovolcanic zone**

J. D. Friedman, in cooperation with R. S. Williams, Jr. (U.S. Air Force Cambridge Research Laboratories), and Gudmundur Pálmsen (National Energy Authority of Iceland) continued investigation of thermal features of Iceland’s neovolcanic zone (see p.C89-C105 for a summary of earlier work in this area), and completed a second series of aerial infrared line-scan surveys in 1968.

*Surtsey volcano.*—Infrared imagery obtained August 1968 revealed continued but diminishing patterns of thermal emission from Surtsey; primary fumaroles and convecting fracture systems are now the major sources of infrared emission from the volcano. Eruptive activity terminated in July 1967.

**Hekla volcano.**—1968 infrared imagery of Hekla volcano, processed by a signal-amplitude level-slicing technique employing a threshold circuit, a 1,000-division potentiometer, and a comparator circuit, applied to the magnetically taped signal, suggests that the most intense thermal emission is related to convecting fractures of the Heklugja eruptive fissure and centers of volcanic activity of 1947–48. These thermal features are interpreted as representing long-continuing posteruptive activity following the pattern noted after the eruptions of A.D. 1766 and 1845, but a small, new thermal anomaly northwest of the summit crater and other changes were noted since 1966.

**Kverkfjöll subglacial thermal area.**—At Kverkfjöll, 1968 aerial infrared surveys confirm that thermal activity first imaged in 1966 is continuing below the normal edge of the ice sheet Vatnajökull. Ice perforations over hydrothermal features, a large ice cauldron (570 × 630 m), and concentric ice fractures convecting thermally were identified by comparing infrared imagery with infrared Ektachrome aerial photographs of the west Kverkfjöll district. Changes in the points of thermal emission since the 1966 infrared surveys, following the emergence of a new solfatara on May 24, 1968, southeast of the glacial melt-water lake Jökullón, were confirmed by the signal-amplitude level-slicing technique. A large, distinctly warm (13°C) melt-water stream emerging from the snout of Kverkfjöll subglacial outlet lobe, 6 km to the north, appeared on both 1966 and 1968 imagery, providing additional confirmation of the persistence of large-scale subglacial thermal activity in this almost inaccessible region.

**Torfajökull thermal area.**—Kristján Saemundsson (National Energy Authority of Iceland), utilizing infrared imagery obtained in the cooperative United States–Iceland infrared survey project and supported by a U.S. Geological Survey contract, has mapped extensive solfatara fields around the postglacial and probably historic rhyolitic lava flow of Hrafninnusker in the Torfajökull thermal area (the largest in Iceland) north of Myrdalsjökull. Saemundsson reports that the majority of the hydrothermal features identified by means of the infrared imagery are located within an
inferred subsided caldera or ring fracture system 12 km in diameter.

Reykjanes thermal area.—A subsurface temperature map of the Reykjanes thermal area, based on 0.5-m depth measurements made with an Atkins thermistor probe system on a grid-traverse plan, was completed in September 1968 under the supervision of Gudmundur Pálsson, supported by a U.S. Geological Survey contract. This map will be used in conjunction with a surface-temperature map to evaluate 1966 and 1968 infrared imagery of the Reykjanes thermal area.

Infrared Ektachrome photography of Iceland

J. D. Friedman, working in cooperation with R. S. Williams, Jr. (U.S. Air Force Cambridge Research Laboratory), Signdur Thórarinsson (Museum of Natural History of Iceland), and Harald Svensson (Lund University, Sweden), identified two areas of polygonal patterned ground features, heretofore unmapped, south of the river Tungmáa at Búðarháls, utilizing infrared Ektachrome 9 × 9-inch photographs, obtained with a K-17 cartographic aerial camera in August 1968 over selected parts of Iceland's central upland. The polygonal features occur over a thick sequence of tephra from historical eruptions of Hekla.

X-band radar mosaic—Massachusetts

The first X-band side-looking radar mosaic was made of the State of Massachusetts by the Grumman Aircraft Engineering Corp., on contract to the Geological Survey. Both east- and west-looking views were provided and are now being analyzed. Although the X-band imagery has somewhat poorer resolution than K-band imagery, acquired from earlier missions, significant geologic information was obtained, according to L. R. Page and coworkers. Glacial features such as outwash plains and drumlins, structural features such as folds and faults, and rock types having distinctive weathering characteristics are clearly portrayed.

Geothermal power studies

R. M. Moxham completed thermal infrared studies of The Geysers geothermal area, California (p. C106–C122) where aerial surveys indicate that the principal high-temperature zones are in part limited (at the surface) on the southwest by structural lineaments; their northeast extent tends to be more diffuse. An arcuate radiance pattern of slightly elevated surface temperatures, extends beyond the northwest present limit of steam production at the Sulphur Banks. The arcuate zone seems to coincide with a temperature difference measured on the surface, and with a mapped fault, as well. There are other slightly elevated radiance patterns in Big Sulphur Creek valley, but their significance is not known. The radiance in Big Sulphur Creek valley, except for the hydrothermal alteration zones, is not exceptional; that is, there is little evidence of a regional geothermal anomaly at the surface in The Geysers area.

Multispectral geochemical prospecting

H. L. Cannon conducted preliminary plant studies at a disseminated porphyry deposit containing 0.2 to 0.4 percent copper and up to 0.1 percent molybdenum near Catheart Mountain, Maine. Forty-six species of flora were studied at 7 copper-molybdenum geochemical sampling stations and 13 stations on barren ground, and pertinent relationships important to remote sensing were found. A difference was found in plant species growing on mineralized ground which may be discernible in aerial photographs. Of particular significance, is the increase of pine and cedar on mineralized ground. The vegetation contains unusually large amounts of copper and molybdenum.

Vegetation rooted in soil of high copper content exhibits symptoms of chlorosis or yellowing of the leaves that may affect reflectance. Plants or parts of plants of many species in the area have natural fluorescence (a species characteristic not related to mineralization) which, when coupled with chlorosis, may enhance reflectance differences on molybdenium-bearing ground.

F. C. Canney, who conducted the geochemical sampling in the same area, and Edward Yost (Long Island University), on contract to the Geological Survey, have conducted ground-based surveys of the reflectance characteristics of vegetation on mineralized and barren ground. Preliminary analyses of reflectance spectra of live plants show that near-infrared reflectance decreases markedly for red spruce and increases markedly for balsam fir in areas where soil contains relatively high concentrations of copper and molybdenum. These studies are aimed at assessing the use of near-infrared photographic or imaging airborne systems to discriminate stressed vegetation in geochemically anomalous areas.

Marine resource applications

P. D. Snavely, Jr., and N. S. MacLeod found thermal infrared imagery from NASA aircraft useful in studying the effluents and sediment distribution patterns of various rivers of the Oregon-Washington coast. The purpose was to study the dynamics of the effluent and shoreline currents as they might relate to placer deposits. Wave-cut terraces and giant ripple marks in tidal flats were investigated.

H. L. Berryhill, Jr., compared pre- and post-hurricane (Beulah, September 1967) photography, spanning 19 years of the Padre Island-Laguna Madre area near
APPLICATIONS TO GEOLOGIC INVESTIGATIONS

Corpus Christi, Tex. From this photography he was able to calculate the rate of sand dune migration for this period of time.

These and subsequent data will also enable him to determine the healing rate of several channels that were cut through Padre Island into Laguna Madre by abnormally high tides.

Data handling and interpretation techniques

Infrared data, obtained on magnetic tape, of hot springs and geothermal phenomena in Yellowstone Park by the University of Michigan Infrared and Optical Sensor Laboratory for the U.S. Geological Survey with NASA support have been processed by analog computer. In one series, separate images were obtained for different intervals of temperature of the ground surface. Successive printouts, representing 1.2°C intervals of surface temperature, were made from the hottest (brightest) portion of the hot springs to the background surface temperature. Electronic contour displays showing lines of equal heat intensity were also printed out and evaluated by D. E. White and L. D. Miller. In a test area near Old Faithful geyser, heat-flow contours were mapped, utilizing individual heavy snowfalls as calorimeters. The heat-flow contours permitted semiquantitative calibration of geothermal anomalies of the lowest intensity detected in the computer-processed infrared data. This lowest limit is on the order of 150 to 500 μcal/cm²/sec, or about 100 to 300 times the world average of conductive heat flow.

H. W. Smedes and K. L. Pierce reported that considerable progress was made in experiments to use analog and digital computer processing techniques on multispectral data acquired by the University of Michigan with its 12-channel optical mechanical scanner. Analog processes enabled them to select optimum spectral bands for the development of target signatures of several rock and vegetation types in a selected area of Yellowstone Park. These were then digitally processed at the Purdue University Laboratory for Agricultural Remote Sensing and resulted in a computer-printout geologic map of the area. In this classification printout seven categories of materials were produced including three rock types. Further experimentation with these data are planned.

E. T. Ruppel developed a four-projector color additive viewing device for analysis of multispectral photography of the Yellowstone Park area. Although he was unsuccessful in using the method to distinguish bedrock types in the northern part of the park he found that it did enhance recognition of some vegetation types and surficial materials.

Luminescence

A prototype Fraunhofer line-discriminator suitable for detection of luminescent materials from low-flying aircraft was built by the Perkin-Elmer Corp. Key components are two Fabry-Perot filters with half-widths of less than 1A and a peak transmission of more than 50 percent. One filter is thermostatically tuned to a selected Fraunhofer line, and the other filter to a convenient point on the continuum adjacent to the line. Low-noise photomultipliers and choppers permit the instrument to look alternately down at the ground and up at the sky through both filters, thereby monitoring the ratio of the Fraunhofer line central intensity to the continuum in each look. An analog computer compares the line-depth ratio in each look and converts any differences that may be present into a signal that is proportional to the intensity of luminescence in a ground target.

Initial tank tests have been performed by W. P. Hemphill and G. E. Stoertz on Rhodamine WT, a luminescent dye used as a tracer by hydrologists in studies of current dynamics in rivers and estuaries. These tests show that the instrument responds to dye concentrations of less than 3 ppb in one-half meter of water. This is substantially more sensitive than was originally hoped for the prototype instrument.

Flight tests have been planned which will help to determine the suitability and capability of the instrument to aid in the study of bay and estuarine dynamics.

Satellite telemetry of earthquake and volcano data

W. H. Jackson and J. P. Eaton evaluated instrumentation, power sources, and relative costs of relaying data from ground-based earthquake and volcano monitoring systems via Earth Resources Technology Satellites (ERTS) and by alternative means. Seismic-event counters and tilt meters appear to be prime ground instruments for data relay in remote areas of volcanic activity. A seismic network on the San Andreas fault, California, has served to test telephone and microwave transmission links. Five instrument stations are also being planned for the Hawaiian Islands, and others are being considered for the Aleutian Islands chain. Other instruments, such as extensometers and geodolites (laser distance-measuring devices) may be required in remote active earthquake regions to thoroughly understand strain and small distance changes due to tectonic activity. Current testing of these instruments is aimed at condensing the data bulk and determining the most suitable combination of instruments to form ground monitoring platforms that will be used in a network to be established in the Hawaiian Islands, and others are being considered for the Aleutian Islands chain. Other instruments, such as extensometers and geodolites (laser distance-measuring devices) may be required in remote active earthquake regions to thoroughly understand strain and small distance changes due to tectonic activity. Current testing of these instruments is aimed at condensing the data bulk and determining the most suitable combination of instruments to form ground monitoring platforms that will be used in a network to be established in the Hawaiian Islands, and others are being considered for the Aleutian Islands chain. Other instruments, such as extensometers and geodolites (laser distance-measuring devices) may be required in remote active earthquake regions to thoroughly understand strain and small distance changes due to tectonic activity. Current testing of these instruments is aimed at condensing the data bulk and determining the most suitable combination of instruments to form ground monitoring platforms that will be used in a network to be established in the Hawaiian
Islands for satellite relay experiments. If successful, similar platforms may eventually be installed in the circum-Pacific region and elsewhere to develop a disaster warning system.

APPLICATIONS TO HYDROLOGIC INVESTIGATIONS

Remote-sensing research directed in fiscal year 1969 to water problems included two projects that are using multispectral scanners for discrimination of terrain and water features. Continued empirical evaluation of photographs and images led to several significant conclusions: (1) color-infrared film is the most widely usable sensor because of its spectral response and ease of use, (2) multispectral scanners hold a great promise for future research and eventual operational use because of their amenability to automated data processing and their flexibility, and (3) repetitive coverage of dynamic phenomena is needed for complete evaluation of hydrologic systems.

Mono Lake, California-Nevada

Infrared imagery was used by R. J. P. Lyon and Keenan Lee (both of Stanford University) in an attempt to detect, delineate, and evaluate the discharge of springs at Mono Lake. Analysis of the thermal variations in the imagery shows a number of shoreline springs and their discharges. Some of the smaller anomalies that were recognizable were spring discharges of (a) less than 1 gpm with a temperature difference between spring and lake of 26°C, (b) 2 gpm with a temperature difference of 8.5°C, (c) 12 gpm with a temperature difference of 1.5°C, and (d) 120 gpm with a temperature difference of 1°C. Additional results were the detection of previously unknown springs and an apparent surface expression of shallow sublake topography.

Infrared imagery and photography of the Anchorage area, Alaska

W. W. Barnwell and Chester Zenone continued their study of infrared imagery and photography of the Anchorage area. The terminal positions and the depositional patterns of the two large glacial lobes that last covered the area can be discerned on the imagery, whereas other portions of the imagery show the entire Anchorage lowland. The data were obtained in early May 1967, when streams and lakes were virtually ice free, but when the ground was still frozen just below the surface. Drainage patterns are clearly discerned on infrared imagery and show the relatively warmer streams and lakes sharply differentiated from the colder terrain features. Infrared imagery was also used to distinguish poorly drained areas underlain by fine-grained soil from the well-drained areas underlain by coarser material. Areas underlain by fine-grained materials thaw more slowly and register as cold areas on the imagery.

Infrared color photographs give a much better definition of terrestrial features than other types of aerial photographs used so far in the Anchorage area. They highlight subtle changes in vegetation and can be used in conjunction with the imagery to distinguish "cold wet" areas from "warm dry" areas. Examination of water features on the photographs indicates that a light blue-gray tone is indicative of a high silt content in the water. This is exemplified by the light blue-gray color of the glacial silt-laden waters of the Eagle, Matanuska, and Knik Rivers and Knik Arm, in contrast to the dark, clear blue of the many clear-water lakes in the area.

Hydrobiology of the Florida Everglades

A strip of the Everglades, 42,000 ft long and 2,000 ft wide near Miami, Fla., was mapped by A. L. Higer and M. C. Kolipinski, using a digital computer and the taped imagery from an 18-channel optical-mechanical scanner. The spectral signatures of various plant communities, limestone outcrops, and a variety of water depths were identified by using a combination of wavelengths between 0.4 and 1.0 μ. The areas of 10 different signatures were separately delineated on transparent film, and each was assigned a color. The films were superimposed and photographed to produce a color mosaic for additional study.

Sinkhole formation in Florida

One of the objectives of this project is to develop techniques by which sinkhole collapse in the Alafia and Peace River basin areas can be recognized or predicted by using infrared and multiband imagery and infrared photography. A first appraisal of the results was completed by A. E. Coker, and these appear favorable. Airborne data were collected cooperatively by the U.S. Geological Survey and the University of Michigan near Bartow, Fla., in September 1967, using a multispectral scanner (0.4–14.0 μ range) and color infrared film.

As a first step, the characteristic electromagnetic spectral signatures for the hydrogeologic features of this area were established by using similar processing techniques and equipment of the University of Michigan's Infrared and Optical Sensor Laboratory. Thermal patterns of features related to sinkhole formation were discriminated on the infrared data by using the University of Michigan's analog computer. Most important of these were patterns showing mois-
Thermal loading of Roxboro Lake, N.C.

J. F. Turner, Jr., analyzed infrared imagery in the 8 to 14 µm band which shows the water-surface temperature distribution and thermal dissipation patterns at Roxboro Lake—a 3,750-acre cooling reservoir for a large steam-electric generating plant in north-central North Carolina.

The imagery was calibrated with surface-temperature data from a monitoring network and thermal surveys, and indicates that thermal loading affects a surface area of about 800 to 1,000 acres. The data also showed a distinct thermal boundary or interface of hot and cool water within the artificially heated area of the reservoir. The interface was the result of wind movement and circulation of water through the reservoir. As heated water spread across the water surface in all directions, the down-lake wind movement accompanied by the natural down-lake flow of water halted the up-lake spread of heated water, resulting in a discontinuity in surface temperatures of about 5°F. Surface temperatures in the heated area ranged from 63.5°F to about 90°F during collection of the imagery data. Portions of the reservoir not affected by thermal loading had surface temperatures averaging about 63°F.

Lakes in west-central Florida

Infrared imagery and infrared color, color, and black and white photography were used by J. W. Stewart to study lake hydrology in a karst environment and to systematically classify lakes and their shoreline features. Part of the area is subject to active sinkhole development and intensive urban growth, citrus-grove farming, and cattle ranching.

The data were collected over two well-defined chains of lakes that represent contrasting topographic and geologic settings, during a period of high water levels. The lakes are of different origins and in various stages of development. Additional data are scheduled to be collected during the dry season when water demands are greatest and water levels are at a minimum.

The photographs recorded distinct color differences in a number of lakes throughout the area. Generally, those lakes disturbed by man either by dredging, deepening, channelizing, or discharging waste showed colors different from those of undisturbed lakes. The reason for the color differences is not yet determined. Eutrophication of a number of lakes has occurred owing to enrichment of lake water by sulfates or nitrates probably derived by leaching of fertilizers by irrigation water. Some types of plant growth on lake surfaces were identified by their characteristic colors on infrared photography. Additional data will be collected under contrasting conditions of hydrologic stress to establish the effects of seasonal changes during dry and wet periods on lakes and on other components of the hydrologic system.

South Carolina coastal plain

Airborne infrared imagery along the Savannah River in South Carolina showed cold spots in a 20-mile reach of the river. G. E. Siple tentatively attributed these findings to discharge of water from limestone aquifers cropping out along the Savannah River, or at shallow depths beneath it.

Gila River phreatophyte project, Arizona

Color infrared photography obtained on a biweekly basis was used by R. C. Culler to study foliation and vigor of vegetation as part of the Gila River phreatophyte project. Changes in the optimum color resolution for flood-plain vegetation were recorded by using color correction filters CC20B and CC30M in addition to the required Wratten 12. Quantitative interpretation was then made with a transmittance densitometer. A bright red represents early spring grasses in the March 22, 1968, photography, and this color extends to the thickets of saltcedar and mesquite as the season progresses and leaves form on the trees. A frost on April 20 partially defoliated the saltcedar, and this was recorded on the May 3 photography as a decrease in the red color. The intensity of red continued to increase to a peak in July and stayed at this level through the middle of August. Beginning in late August, the intensity of red gradually decreased as the leaves approached dormancy. Spatial variability of vegetation density was identified by changes in the intensity of the red, and moist ground was recorded as a dark green by the three-filter combination.

Sabine Lake estuary, Texas-Louisiana

D. C. Hahl and K. W. Ratzlaff reported that infrared imagery collected during an overflight of the Sabine-Neches Rivers estuary shows water temperature differences, flow patterns, and areas affected by heated water discharge. Color photographs taken of the Sabine Lake-Sabine Pass area during ebb tide also showed the existing flow patterns.

Color tone changes on photographs of an area containing water of measured low dissolved-oxygen content were noticed. Further data must be collected to ascertain whether or not the color tone changes can actually be correlated with dissolved oxygen or with other water-quality parameters.
Springs and seeps, Lehigh River, Pa.

Predawn infrared imagery taken August 1, 1968, was used by C. R. Wood to locate numerous springs and seeps along the banks of the Lehigh River. The capacity of the imager to detect these springs was enhanced somewhat, because the river and land temperatures were close (22°C–26°C) when the imagery was collected. As a result, the cooler water in the springs (10°C–15°C) along the banks of the river stands out clearly on the imagery. Springs flowing at less than 1 gpm can be seen on the imagery.

Estuarine vegetation mapping

R. R. Anderson continued to collect and analyze color infrared aerial photography over the Patuxent River estuary, Maryland, for research in water-quality and shore vegetation. Various filters, including the Wratten 15-G, 25-A, and 57 are being used with color-infrared film to determine which characteristics of pollutants and phytoplankton blooms are enhanced by a given filter or filter combination. Results thus far indicate that color infrared film is useful in (a) determining the source and extent of silt addition to estuarine water, (b) delineating areas with excess nutrification through phytoplankton blooms, (c) determining general salinity conditions in estuarine water through indicator plant species, and (d) delineating marsh plant communities, including those necessary for maintenance of wildlife populations.

Florida west coast springs

Infrared imagery was used in a continuing study to locate subaqueous springs or vents along Florida's west coast where the piezometric surface map indicates submarine discharge of ground water. The imagery of selected areas was examined by R. N. Cherry. The examination led to locating vents in the sea floor which occasionally discharge water. Although no definite conclusions about the amount of water discharged from the vents can be drawn from the data, subtle tonal differences in the imagery suggest the presence of additional vents. Seasonal variations in water temperature appear to be a principal factor in locating the vents and will be considered in the timing of future data collection missions.
GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

In the past 25 years, the U.S. Geological Survey has become involved with international activities of increasing scope and complexity including technical assistance, scientific exchange and cooperative research investigations, participation in international commissions, representation in international earth science associations, and training or supervision of participant scientists from abroad. This growth in the Survey's international program is a result not only of the need to help develop geological agencies and resources programs to support economic growth in the less-developed parts of the world, but also of the importance of stimulating collaboration and cooperative research with earth scientists in other lands on geologic problems or resources that are important to the United States.

Technical assistance activities in developing countries have involved the largest and most continuous commitment of Geological Survey personnel. During the past quarter of a century the Geological Survey has provided earth-science specialists for about 900 assignments in more than 70 countries. This assistance is presently provided at the request of recipient countries, under the authority of the Foreign Assistance Act of 1961, as amended, in cooperation with the U.S. Department of State. Part of the responsibility of assigned personnel is to provide on-the-job training for counterparts in the host country.

The impact of the Geological Survey's technical assistance has been especially strong where the Geological Survey has had long-continued programs of assistance in various projects important for national economic development. Most of the Geological Survey's technical assistance projects have been concerned with geologic mapping, appraisal of mineral and water resources, or applied geologic and hydrologic studies concurrent with training or guidance of counterpart scientific personnel and development or strengthening of counterpart institutions. The mapping and resource-appraisal activities have contributed significantly to the assessment of major resources such as the iron resources of the western Serra do Curral \(^{17}\), Minas Gerais, Brazil, and the mineral resources (gold, iron, manganese) of the Barao do Cocais area, also in Minas Gerais (G. C. Simmons, r0246). Applied geologic and hydrologic studies have contributed to the solution of many problems vitally affecting the economic and social development, as for example, an engineering study of the disastrous landslides of Rio de Janeiro and environs, Brazil, (F. O. Jones, r0169) and ground-water studies in the Punjab area, West Pakistan (W. V. Swarzenski, r1887; and G. D. Bennett, M. J. Mundorff, and S. A. Hussain, r0833).

Since the beginning of the Survey's technical assistance program in 1945, more than 1,000 technical and administrative documents have been issued. During calendar year 1968, 76 reports were published and (or) open filed, and 49 technical/administrative documents were prepared (table 3).

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<th>Country or region</th>
<th>Reports or maps prepared</th>
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A199
During fiscal year 1969, in addition to providing in-country on-the-job training, the Geological Survey guided the training in the United States of 91 earth scientists and engineers from 24 countries. Types of assistance given each country during the fiscal year are summarized in table 4. A description of training programs that can be provided in the United States by the U.S. Geological Survey was prepared in manual form for distribution to the Agency for International Development, U.S. Department of State, and other interest-

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1 A, broad program of assistance in developing or strengthening earth-science institutions and cadres; B, broad program of geologic mapping and appraisal of resources; C, special studies of geologic or hydrologic phenomena or resources; D, short-range advisory help on geologic or hydrologic problems and resources.
ed sponsors. This will guide both sponsors and counterpart organizations in planning future training requests.

To date about 1,000 participants have completed academic or intern training in the United States under Geological Survey guidance.

In 1968, more than half of all international technical-assistance activities undertaken by the Geological Survey were financed by loans to the recipient host government or directly by those governments. With this assumption of economic responsibility by host countries, the role of the Survey has become increasingly that of coworker and consultant. This transfer of responsibility is a significant indication of scientific and technical advancement. Science leadership is now emerging in many developing countries, and among indigenous political and economic leaders there is a growing realization of the value of basic mineral- and water-resource information in national economic planning and development.

For a summary of topographic technical-assistance programs, see “International-Assistance Programs” (p. A225) in the section “Topographic Surveys and Mapping.”

In addition to technical assistance and participant training, the Survey participated in a wide range of scientific and technical international-exchange activities and related cooperative investigations, including: (1) bilateral scientific collaboration in volcanology with Japan; (2) multilateral collaboration in mapping the Antarctic; (3) earthquake investigations in the CENTO region, including help in organizing a seminar in earthquake disaster minimization and scientific studies of earthquake effects in eastern Iran; (4) ecological study in the deserts of Mexico in support of domestic arid-zone research; (5) oceanographic studies in the Carribean and the Gulf of Mexico; (6) arrangements abroad for testing of remote-sensor systems, including experimental remote-sensing in collaboration with Brazilian and Mexican scientists and experimentation with application of gamma-ray scintillation equipment to geologic mapping in Saudi Arabia.


**SUMMARY BY COUNTRIES**

**BRAZIL**

**Mineral investigations in Bahia**

Mineral investigations in the State of Bahia (locality 1, index map) under the cooperative program between the National Department of Mineral Production (DNPM) and the U.S. Geological Survey (USGS) have delimited five metallogenic provinces that are related to the regional geology, according to R. W. Lewis (USGS) and associates of the DNPM, as follows:

1. A north-trending belt of nonferrous minerals (mainly lead, with scattered manganese), in middle Precambrian metasediments in west-central Bahia.
2. A north-trending belt in eastern Bahia in which copper, chromium, and asbestos are associated with mafic and ultramafic intrusives in Precambrian gneiss, migmatite, and charnockites; platinum metal?, gold, cobalt, and nickel may also be present.
3. A belt of diamond, gold, and tin placers associated with conglomerates of the upper Precambrian Lavras Group in central Bahia.
4. A region of pegmatites containing beryl, tantalum, and mica in Precambrian rocks.
5. A nonmetallic-mineral and bituminous province in Mesozoic sedimentary basins in northeast Bahia.

The association of lead minerals with dolomite and amphibole-rich rock has been found to be a guide for prospecting in the Boquira lead district of Bahia. In the Gentio do Ouro district, placer gold has been traced to quartz veins in gabbro intruding Precambrian or Paleozoic quartzites. This association presents new possibilities for finding gold in other areas of
magnetic rocks in Bahia. To assist the miners in recovering the placer gold in the semiarid Gentio do Ouro, J. B. Pomerene designed and built a rocker-type blower equipped with bellows that is reasonably effective in producing concentrates from dry sand and gravel. It is available to the miners for experimentation and copying.

Preliminary studies along the Maragojipe fault in Bahia, which separates the Recôncavo sedimentary basin from Precambrian crystalline rocks, confirmed the presence of base-metal mineralization, and proved sampling of soil and stream alluvium to be viable geochemical techniques in this thoroughly leached terrane.

Regional geologic studies in Goiás
C. L. Hummel (USGS), Iran Machado, and C. O. Berbert (DNPM) reported that more than 100 ultramafic intrusive bodies have been found in the serpentine belt of Goiás (loc. 2), whereas only 15 were known 1½ years ago. Several methods of exploration, including geophysics and geochemistry, are being used to make a comprehensive geological reconnaissance study of the region, with special attention to presence of economic mineral deposits. Promising deposits of nickel, cobalt, copper, chromite, and asbestos have already been found, probably associated with ultramafic rocks.

Tungsten investigations in Rio Grande do Norte
The Brejui mine, near Currais Novas, Rio Grande do Norte (loc. 3), has produced scheelite for about 25 years from tactite in Precambrian crystalline rock. Mineral-resource studies by R. H. Nagell (USGS) and Frederico Barbosa (DNPM) show that reserves in all categories total more than 2 million tons of ore; measured reserves contain 0.7 percent WO₃ and 0.18 percent Mo. Molybdenite in the ore may be an additional economic mineral that heretofore has not been recovered.

Origin of mineralized water in Precambrian rocks of the Upper Paraíba Basin, Paraíba
According to S. L. Schoff most of the ground water in Precambrian rocks in a 12,000-sq-mi area of the Upper Rio Paraíba basin in northeast Brazil is of inferior chemical quality. The average dissolved-solids content of the water is 4,300 mg/l but ranges between extremes of 334 and 25,000 mg/l. The chemical quality of ground water strongly resembles that of sea water. Chloride is the predominant anion, and magnesium predominates over calcium in the ground water. It is suggested that the ground water contains some residual sea water, introduced during a Late Cretaceous marine invasion of the land, and that this water has been diluted by meteoric water and largely flushed out of the rocks, a process that is still incomplete but is continuing.

Ground water in the Teresina-Campo Maior area, Pinuí
H. G. Rodis (USGS) and Edson Suzinski (hyd-ogeologist with the Brazilian Superintendence for the Development of the Northeast) report that the ground-water reservoir of the Teresina-Campo Maior area is contained chiefly in sandstone aquifers of six sedimentary formations ranging from Middle Devonian to Pennsylvanian age. These aquifers are tapped by some 200 drilled wells ranging from 40 to 500 m in depth. Currently the annual draft in the area from these aquifers is about 600,000 cu m, half of which is used for municipal supply and the rest for rural household use and irrigation. Although the present use of ground water for irrigation is only about 600,000 cu m annually, it is expected to increase substantially during the next decade. The water is of excellent chemical quality and is generally acceptable for most uses.

CENTO
The third annual Central Treaty Organization (CENTO) training course in geologic mapping techniques was held from July 15 to September 22, 1968, in Iran under the supervision of E. H. Bailey, with the assistance of J. W. Barnes (University of Wales, College of Swansea), and Isik Ozpeker (Istanbul Technical University, Turkey). For two weeks Donald Schlick (U.S. Bureau of Mines) gave instruction in mining and mine evaluation. The course was supported logistically by the Geological Survey of Iran whose staff also assembled the results of all earlier work in the area under study. The course was held at the Lakan lead-zinc mine in the eastern Zagros Mountains. Postgraduate geologists from Turkey, Iran, and Pakistan were given instruction in planarite mapping, mapping on aerial photographs, underground mapping, geochemical prospecting, and other techniques. Although the emphasis of the program was on field methods, the resulting maps and reports contributed new data regarding the origin of the Lakan ore deposits and permitted suggestions regarding areas where more ore might be sought. A report covering all aspects of the study is being prepared and will be published by CENTO.

COLOMBIA
Geologic mapping
The U.S. Geological Survey in cooperation with the Colombia Ministry of Mines and Petroleum has com-
completed geologic studies in four zones selected for economical mineral deposits.

**Zone I.**—Zone I, which includes 7,700 sq mi of rugged terrain and complex geology in the Sierra Nevada de Santa Marta in the Departments of Magdalena and La Guajira (locality I, index map), was mapped by C. M. Tschanz and counterparts. This area is of great scientific interest because it provides evidence for such processes as convection cells in the mantle, continental accretion, continental drift, the relationship of two orogens to underthrust continental margins, and the mechanism by which batholiths are emplaced into a continental plate that was disrupted by laterally spreading convection currents from a former oceanic rift. Many major structures and orogenic belts in the Sierra Nevada can be correlated widely in northern Colombia. Two parallel orogens can be correlated with the coastal orogenic belt as far eastward as Trinidad. The area consists of three tectonic provinces, known as the Sevilla arch orogen, the granulite province, and the Eocene orogen near Santa Marta. Each province contains metamorphic rocks formed during orogenies of different ages, but two episodes of regional metamorphism are superimposed only in the central Sevilla arch orogen.

A granulite province to the southeast of the Sevilla arch province appears to be a disrupted fragment of the Guyana Shield that was thrust northwestward. The Precambrian granulites give Rb/Sr isotopic ages of between 752 ±70 and 1,300 ±100 m.y. and K/Ar age of 940 ±34 m.y. In Jurassic time the granulite province was greatly expanded along spreading tensional rifts which were passively intruded in three stages by batholiths ranging in K/Ar isotopic age from 162 to 202 m.y. The oldest of these was intruded along a major northeast-trending wrench fault that separates the granulite province from the Sevilla arch province. Fault-bounded blocks of granulite apparently drifted apart in all directions during the intrusion of the Jurassic batholiths. Faulting and intrusion are interpreted to be related to underthrusting along the former continental margin in response to the southeastward lateral movement of convection currents in the mantle. The same process may have caused regional metamorphism of the Sevilla arch orogen. Reactivation of the system in Eocene time may have produced the Eocene orogen near Santa Marta which extends northeastward to the tip of the Guajira Peninsula and possibly eastward to Trinidad.

The Eocene orogen appears to be offset by wrench faults along the north and west sides of the Sierra Nevada, or else it has been overridden by a thrust plate from the granulite province. Major structural problems are still unresolved, owing to the difficulty of separating wrench faults of early Mesozoic and early Tertiary age.

**Zone II.**—About half of zone II (loc. 2) in the Departments of Antioquia and Caldas, covering an area of 15,730 sq mi, has been mapped geologically by Tomas Feininger, R. B. Hall, and counterpart geologists. The mapping showed that previously unrecognized major wrench faults are fundamental tectonic elements in the northern Central Andean Cordillera of Colombia. Four geosynclinal sequences of sedimentary rocks and associated igneous rocks that range in age from Precambrian to Cretaceous are recognized. The rocks are chiefly eugeosynclinal and generally are progressively younger westward. Regional metamorphic isograds were defined. These relations may indicate that continental accretion has been an active process in this part of South America since Precambrian time.

Nickeliferous laterites at Ure, containing 0.25 to 0.40 percent Ni and 25 to 45 percent Fe in the upper 2 to 4 m of laterite and 1 to 2 percent Ni and 10 to 25 percent Fe at depths between 4 and 9 m, were found to have an overall tenor of about 0.77 percent Ni and 28 percent iron in about 23 million metric tons of laterite. Large reserves of carbonate rocks were mapped, and the talc deposits at Yarumal were explored by drilling.

**Zone III.**—During 1966 D. E. Ward, Richard Goldsmith and counterparts mapped 1,146 sq mi, bringing the total area mapped in zone III (loc. 3) to 3,270 sq mi, in the Departments of Santander, Norte de Santander, and Boyaca. The thick section of Devonian rocks exposed in the southern part of zone III was found to have major lithologic variations across a complexly faulted syncline which also contains rocks rang-
SUMMARY BY COUNTRIES

Phosphate studies
Studies by E. K. Maughan and counterparts disclosed extensive phosphorite deposits containing pellletal apatite, probably carbonate fluorapatite. The main exploitable zone is in the lower part of the Galembro Member of the La Luna Formation and equivalent strata of late Cretaceous age (Santonian?) that underlie wide areas in the Departments of Santander, Norte de Santander, and Boyacá. Favorable indications of phosphate were found in the Cologollo Formation and its lateral equivalent, the Simiti Formation of probable Cenomanian age, which underlie the La Luna Formation. A third potentially economic phosphorite horizon is at the base of the Umir Formation and its equivalent, the Colón Shale (Maestrichtian?) that overlap the La Luna. Phosphorite in the Umir Formation consists of detrital reworked grains derived by erosion of pellletal phosphate from the La Luna Formation and deposited as a younger basal microconglomerate above the intervening unconformity.

The phosphate-bearing beds range from 1- to 5-m in thickness, and generally have moderate to steep dip; individual deposits may extend from several kilometers to 20 km along strike. Most outcrops are intensely weathered; thus, the original nature and compositor of the rocks cannot be easily judged, and deep drilling is essential to determine ore grades. Some phosphorite deposits appear to be bonded by clay and silica, but much of the total reserve is cemented by calcite.

CONGO

Ground water in the Kinshasa area
The terraces of the Congo River for about 30 mi east of the city of Kinshasa (Leopoldville) are underlain by buried channels which contain highly permeable water-bearing deposits of sand and gravel. According to G. C. Tibbitts, Jr., these water-bearing deposits potentially should yield 1 to 3 cfs to properly located wells of modern design. Extensive exploratory drilling is needed to locate the buried channels beneath the terraces, together with pumping tests to evaluate aquifer hydraulics.

EL SALVADOR

Geothermal investigations
At the request of the United Nations, D. E. White visited El Salvador to evaluate the United Nations Development Program–Government of El Salvador program of geothermal-energy exploration. The five exploratory wells drilled in the period March to September 1968 range from 2,000 to 5,000 feet in depth. One well is producing satisfactorily. White found that permeability in two others is too low for adequate production. Unexpectedly, the producing well is yielding a brine of about half the salinity of sea water and presents serious problems in disposal of effluent because of the high salt and boron content. Reinjection may be the only solution to this problem.

GUYANA

Geochemical research
Soils around serpentinite were found by B. E. Tilpatrick and Geological Survey Department of Guyana associates to be enriched in chromium, cobalt, manganese, and vanadium under conditions of deep tropical weathering in Guyana; nickel, however, never exceeds 5,000 ppm, owing to loss of nickel in weather-
ing. Cobalt is considerably enriched, possibly because of the scavenging action of manganese. Copper content follows manganese in the soils, but not as closely as cobalt. Chromium seems to have remained nearly constant during weathering.

M. E. Shaffer and counterparts found that, under similar conditions, topographic relief affects the trace-element content of soils, but not to a degree which would prevent detection of variation in bedrock lithology. The cold-extractable field test for cobalt proved to be excellent as a guide to copper, which made less marked anomalies than cobalt. The best regimen of geochemical exploration techniques was found to be the use of the cold-extractable cobalt test in the field, followed by total copper, gold, and possibly cobalt analyses in the laboratory, and semiquantitative spectrographic analyses of a few selected samples.

**INDIA**

**Phosphate investigations**

Studies of phosphates of the Mussoorie area by the Geological Survey of India, National Mineral Development Corporation, and the Fertilizer Corporation of India, with the assistance of D. F. Davidson and S. A. Stanin, and metallurgical studies by the Indian Bureau of Mines under the guidance of P. C. Good, metallurgist (U.S. Bureau of Mines), indicate that the deposits may be lower in grade and more restricted geographically than previously thought. A new program designed to test the deposits more thoroughly has reoriented the Government of India's appraisal of these resources. New emphasis is being given to deep trenching, aditng, drilling, stratigraphic studies, and bulk sampling, as well as to the appropriate use of mass produced laboratory analyses as an exploration tool. L. F. Rader spent 2 months at laboratories of the Geological Survey of India to help set up a mass production laboratory system to obtain the required analytical data.

**Water-resources study of the Narmada River basin, west-central India**

According to G. E. Ferguson and Allen Sinnott, the Narmada River flows in a structural trough or rift valley which is filled in part with water-bearing alluvial deposits. Although ground water in the valley was increasingly developed during the past decade for supplemental irrigation, the surface flow of the Narmada is practically undeveloped at present (1968). The States of Madhya Pradesh and Gujarat, however, have extensive plans for major development works on the river. As development proceeds but before full development is attained, a comprehensive water-resources appraisal has been recommended that would evaluate alternatives in the conjunctive use of the surface and ground-water resources of the basin.

**JORDAN**

**Oil shale as energy source**

The Hashemite Kingdom of Jordan, through the U.S. Agency for International Development, received assistance in the evaluation of Upper Cretaceous oil shales in the El Lajjun region of northwestern Jordan. V. E. Swanson estimated that there are several tens of millions of tons of oil shale that will yield 20 to 45 gal per ton of relatively high quality oil. Additional large probable resources were found to the south and east. As Jordan has no coal or petroleum, this source of energy may be developed in the near future. Testing of the shale by modified Fischer oil assay retorts showed that 4 samples of oil shale in the Belga Series (Upper Cretaceous) contain 20.0 to 41.4 gal per ton of oil, and confirmed field estimates. Ash from the oil shale contains in percent: P, 3; Cr, 0.15; Cu, 0.05; Mo, 0.05; Ni, 0.05; V, 0.05; and Zn, 0.15. Phosphate may be mined as a coproduct.

**LIBERIA**

**Geochronology**

As part of the Geologic Exploration and Resources Appraisal Program (GERA), R. W. White and G. W. Leo and counterparts of the Liberian Geological Survey have recognized a northwest-trending tectonic belt that extends more than 200 miles along the coast of Liberia between Greenville and the Sierra Leone border. In the belt, northwest-trending strikes in crystalline rocks contrast with northeast strikes in most other areas of Liberia. The crystalline rocks include pyroxene and hornblende orthogranulites and paragranulites, amphibolite, biotite-rich paragneiss, schists, iron-formation, and a lesser proportion of granitic rocks than is typical in adjacent areas. Initial radiometric age determinations by P. M. Hurley and co-workers (Massachusetts Institute of Technology) indicate that the northwest-trending belt may represent a late Precambrian (about 500-700 m.y.) tectonic zone, continuous with a similar zone in Sierra Leone, and contemporaneous with a widespread Pan-African thermo-tectonic episode.

**Geologic mapping**

R. W. White, mapping the sedimentary basin on the coast of Liberia between Monrovia and Buchanan, recognized a stratigraphic succession consisting of: an older sandstone unit, cut by late Triassic diabase dikes.
and sills; an extrusive basalt which locally overlies the older sandstone; a younger sandstone and conglomerate unit determined through palynologic study by R. A. Scott to be of Albian or younger age; a third sandstone presumably of Tertiary age; and the youngest sedimentary unit of unconsolidated sands and clays of presumed Quaternary age.

**Geophysical studies**

As part of the GERA program, an airborne geophysical survey of Liberia was completed during 1968. The geophysical data indicate that a sequence of sedimentary rock possibly several kilometers thick is present on the continental shelf. J. C. Behrendt, working with C. S. Wotorson (Liberian Geological Survey, LGS), on the basis of depth estimates to magnetic basement, delineated several basins where sedimentary thicknesses probably exceed 3 km. The thickest sequence, probably more than 5 km, lies between long 10°20' W. and 11°30' W. This interpretation of the magnetic data has stimulated interest in offshore petroleum exploration, and several firms have already undertaken preliminary seismic reflection surveys. The aeromagnetic data provide a good basis to delineate many anomalies over various rock units in Liberia. The iron-formations are particularly conspicuous, having amplitudes as high as 18,000 gammas. Geologic trends are apparent in the magnetic maps and include a number of linear features that can be traced more than 100 km.

The radioactivity (total count gamma radiation) results show a good correlation with the known bedrock geology and will greatly assist in the preparation of regional geologic maps. In determining the possible significance of the radioactivity, Behrendt compared the amount of K₂O in 27 rock samples throughout Liberia with the radioactivity observed over the sample sites. A linear trend is apparent which is significant at the 1-percent level. Although more analyses are needed, it appears that the radioactivity maps may be used as an indication of potassium (and probably thorium and uranium) content. Previous workers have shown strong correlation between thorium, uranium, and potassium. The samples in the Liberian study did not exceed the 5 percent K₂O amount that corresponds to a 500 counts per second rate. Anomalies higher than 750 counts per second exists in Liberia which can be accounted for only if values of K₂O exceed 8 percent, which is highly unlikely. Therefore, the high radioactivity areas are considered anomalous and probably contain anomalous amounts of thorium and uranium. These are suggested as target areas for prospecting.

**Barite and kyanite deposits**

A concession has been granted by the Government of Liberia for the exploration and possible development of the Gibi barite deposits described by J. B. Pomerene (USGS) and W. E. Stewart (LGS). The concessionaire is currently exploring the deposit by trenching with a bulldozer and shallow air drilling. The results of investigation of the Mount Montro kyanite deposit by S. A. Stinin (USGS) and B. R. Cooper (LGS) (r1015) were published. The report indicates total reserves of approximately 2.5 million tons of kyanite in the deposit, which is favorably situated for development. Chemical and spectrographic analyses of samples presented by Samuel Rosenblum in a short supplemental report show that the raw kyanite compares favorably with commercial deposits in the United States and other places.

**Clay deposits**

Investigations of the Bushrod Island-New Georgia clay deposit near Monrovia by L. V. Blade and Liberian counterparts showed that the clay-rich zone is composed of interlensing clay and very fine grained to fine-grained quartz sand deposited in elongate subparallel troughs that had been eroded in coarse-grained sediments. The troughs are interpreted as abandoned stream channels on a former delta of the St. Paul River. The clay of the deposit is quartz rich and kaolinitic, and the upper part of the deposit is sufficiently weathered to redistribute iron and alumina. Potential indicated reserves are estimated at 7,570,000 tons. Tests of the physical properties of the raw and fired clay are being made to determine specific commercial uses for which the clay may be suitable.

**Silica sand**

Further investigations of the silica sand deposits in the Monrovia area by Samuel Rosenblum (USGS) and S. P. Srivastava (LGS) indicate at least 300 million metric tons of easily minable sand in the coastal area between Paynesville and Marshall. In addition, at least 50 million metric tons of sand represents a potential reserve in the more developed areas and along the Kakata Highway north of Paynesville. Random samples from 15 locations show that the sand consists of 99 percent or more quartz and less than 1 percent heavy minerals. Over 90 percent of the sand is in the usable size range (0.1 to 1.0 mm), and the total iron content analysed in nine samples was 0.00 to 0.17 percent. Refractory minerals, such as kyanite and sillimanite, are negligible. The white sands originated...
from intense weathering and erosion of predominantly granitic gneiss terrane, and deposition in a lagoonal environment.

Geochemical studies

Geochemical soil samples were collected by D. H. Johnson working with B. R. Cooper and A. J. Holmes (both LGS) in examining several base-metal localities in western Liberia for minable deposits, and in evaluating applicability of the methods to base-metal prospecting under tropical conditions. Although minable deposits were not found in the localities examined, geochemical soil sampling methods are considered useful in prospecting for concealed deposits of base metals in Liberia.

Heavy-minerals studies

Cassiterite was identified by Samuel Rosenblum and counterparts in panned heavy-mineral concentrates from several small streams in the vicinity of St. Johns Falls, central Liberia. In 1961, tin was identified spectrographically in similar samples from the same region by geologists of the Liberian American Mining Co. Rosenblum and Carney Johnson (LGS) began a search for the source of the cassiterite in predominantly granitic gneiss terrane overgrown with dense tropical vegetation.

NEPAL

Ground water in the western Terai

W. V. Swarzenski and H. M. Babcock report that the alluvial aquifer underlying the Terai belt of southern Nepal may attain, in places, a thickness of 1,000 feet. This aquifer, as yet largely undeveloped, can potentially yield 1 to 2 cfs, or possibly more, to properly constructed wells. Extensive exploratory drilling is needed, however, to establish the position and areal extent of the most productive water-bearing zones in the aquifer.

NICARAGUA

Geothermal energy

D. E. White, primary advisor to the Government of Nicaragua and the USAID mission, evaluated contract proposals for the development of the San Jacinto-Tisate geothermal area as a practical energy source. Actual exploration is being done by private firms under the careful guidance of the USAID mission. White's recommendations are focused primarily on the San Jacinto-Tisate area but include low-cost geochemical and other techniques that could reveal possible geothermal reservoirs in other areas.

NIGERIA

Chemical quality of water in northern Nigeria, 1965–68

According to R. T. Kiser, the results of 400 chemical analyses have shown that the surface and ground water of northern Nigeria varies widely in dissolved-solids concentration and chemical type, but water from most sources is suitable for drinking by man and livestock. Nearly half the water samples, however, from dug wells in western Chad Basin and the Kerri area are high in nitrate content. Many water samples from boreholes in the Chad and Sokoto Basins have undesirable amounts of iron and manganese. Also water from some ground-water sources, particularly in the Chad Basin, is limited in its suitability for irrigation use, because of salinity, sodium, or bicarbonate hazards. The boron hazard, however, in analyzed samples is practically nonexistent.

Surface-water resources of the Yobe River basin, northern Nigeria

B. E. Colson reporting on 4 years of fieldwork in surface-water investigations in the Yobe River basin of northern Nigeria notes that whereas the upper reaches of the streams of the basin have flashy runoff and high sediment loads, the lower reaches have attenuated runoff with peaks occurring as long as 7 months after the end of the rainy season. Aggradation in the lower reaches of stream channels and in adjacent flood plains is contributing to recurring flooding problems near the towns of Ringim, Hadejia, Nguru, and Gashua. Although channel dredging and protective levees have been considered, these measures are too costly to be economically feasible at present (1968). Building of dams and reservoirs in the upper reaches of the Yobe system would mitigate but not solve the flooding problem, as it is estimated that only 15 to 20 percent of the runoff could be stored economically.

PAKISTAN

Tarbela damsite study

A geological survey, by J. A. Calkins and Pakistani geologists, of the site for the giant Tarbela Dam to be built across the Indus River (locality 1, index map) shows that a major strike-slip fault passes down the river through the damsite. As a result of previous U.S. Geological Survey work in the region to the east, the presence, 15 miles upstream, of the large Darband fault was known. In the survey of the damsite, the Darband fault was identified on the west bank of the Indus 1 mile downstream from the damsite, where it forms a breccia zone 200 to 1,000 feet wide, and separates Precambrian rocks on the west from younger
rocks on the east. Minimum displacements are 10,000 feet of left-lateral movement and 5,000 feet of vertical movement. The fault is not likely to cause problems, however, because it is covered by several hundred feet of river alluvium at the damsite. Regionally, the Darband fault is one of three major strike-slip faults that subdivide the area between the Indus and Jhelum Rivers into four structural blocks.

East Pakistan nonmetals investigations

N. A. Parker (USGS) and Maroof Khan (Geological Survey of Pakistan) found that very large deposits of clay and shale near markets in East Pakistan (loc. 2) can be made suitable for commercial production of lightweight aggregate (r0170) by using bloating techniques. Laboratory muffle-furnace tests have provided bloating temperatures and ranges, thus paving the way for pilot kilns and full production. East Pakistan, with its growing economy, does not have sources of natural aggregates for construction purposes; thus these deposits are of economic interest both to the Pakistani Government and to private industry.

Base-metals investigations, Chitral State

J. A. Calkins and counterpart geologists, working in the Hindu Kush Range of northern Pakistan (loc. 3), found high values of gold (200 ppm) and silver (2,000 ppm), and significant amounts of copper (1,000 ppm), vanadium (7 ppm), and tin (200 ppm by spectrographic analysis of samples from veins carrying lead, antimony, and arsenic. The veins are small but form a mineralized belt 8 miles long between Chitral and Partsan. Antimony is presently being mined at Krinj.

Copper has been widely found in Chitral in the form of chalcopyrite, malachite, and azurite in quartz veins and disseminated grains in greenstone. Copper is also found in marble, slate, schists, and granite. Spectrographic analyses of various sample materials show as much as 30,000 ppm Cu, 5,000 ppm Pb, 2,000 ppm Sb, 1,000 ppm Zn, and 150 ppm Ag. None of the localities is large but they do show copper to be widespread in Chitral.

Chromite investigations

Ultramafic complexes (loc. 4) near Dargai, Peshawar Division, and at Jungtor Ghar near Hindubagh, Quetta Division, West Pakistan, are being studied by D. L. Rossman, together with Zaki Ahmad and other geologists of the Geological Survey of Pakistan for their chromite potential. The Dargai complex is known to be 16 mi long, and extends farther west into the Mohmand Agency, which is inaccessible at present. The deposits were previously regarded as discontinuous and small, but are now known to represent enriched portions of remarkably persistent layers of disseminated chromite in dunite. Two major layer-d zones have been recognized and traced parallel to the long direction of the rock mass. Individual layers as much as 15 ft thick contain 50 percent chromite (46-48 percent Cr2O3 with an Fe:Cr ratio of 1.3). The chromite is of metallurgical grade, but because it is disseminated, is not now exploitable.

The Dargai complex also contains some geologic features important to the understanding of the origin of Alpine-type ultramafic rock complexes. Compositional layering of the two main magnesiurn-rich mineral components (olivine and pyroxene) stril-es uniformly east and dips steeply to the north and south. However, some of the chromite layers in the central northern part of the area transect this structure and dip uniformly 15°N. In places this layering is evident, especially from a distance; it probably represents the original internal disposition of the mass. The steeply dipping layers may represent a fabric produced by differential movement in a process similar to that which produces schistosity in sedimentary rocks. This tectonically developed layering is probably widely present in ultramafic rocks of the Alpine type. Both types of layers can be discerned in the same rock at some places.

The Jungtor Ghar is a thrust block that contains a segment of the metamorphosed basement rock and an ultramafic mass in which the structurally simple sequence of layered dunite and harzburgite are preserved. The Saplaigor Ghar area east of the Jungtor Ghar, where work has just been started, is a similar structural block, and is believed to be a higher part of the same sequence, including gabbro and diorite. The
following general internal sequence is suggested for
the complex, for top to bottom: diorite, gabbro, pyrox-
enite, dunite, alternating dunite and harzburgite, dun-
ite, and metamorphosed basement rock.

In detail the sequence is complex. In addition to the
thick units of dunite, it also occurs as (1) thin layers;
(2) as large masses as much as 3,000 feet long and sev-
eral hundred feet thick which lie at an angle to the
layering; (3) as intrusive bodies in the middle and up-
per part of the ultramafic part of the sequence; and
(4) as a structurally complex zone of altered dunite
and harzburgite in the southern part of both areas.

Chromite is universally associated with dunite, and
is sparsely present in small minable bodies in the basal
dunite zone, but is most abundant in the upper part of
the alternating dunite and harzburgite zone. Chromite
is also present in the upper dunite zone but is low in
chromium and high in iron content. Most chromite oc-
curs near the top of the dunite layers and characteris-
tically as disseminated nodular ore near the top of the
large transgressive dunite bodies. In the intrusive dun-
ites, chromite generally is highly irregular in shape
and random in its position. Some high-grade chromite
deposits near the gabbro probably occur in intrusive
dunite. Differential movement has modified the shape
of the original chromite masses into elongate sword-
shaped masses, most of which lie in the plane of layer-
ing and plunge to the northeast. Deformational struc-
tures and fabrics are common and well shown in most
of the chromite bodies.

Compositional layering near the base of the complex
appears to be parallel to the major rock units, but
higher in the succession the layered structure may
cross rock units at any angle. Exploration should be
concentrated along the upper contacts of the dunite in
layered rocks and the transgressive dunite masses.

Electric-analog studies of brine coning beneath fresh-
water wells in the Punjab region, West Pakistan

G. D. Bennett and M. J. Mundorff (both USGS), and
S. A. Hussain (10833) (West Pakistan Water and
Power Development Authority) report that a graphical
procedure formulated by Morris Muskat to deal with
the problem of water coning beneath oil wells can also
be utilized to study the coning of brine or brackish wa-
ter beneath fresh-water wells, supplied at equilibrium
by uniform areal recharge. Applied to conditions in
the Punjab region of West Pakistan, the procedure
gives results that indicate prospects are good for de-
velopment of wells capable of yielding fresh water above
a stable cone in the underlying brine or brine or brack-
ish water.

SAUDI ARABIA

Metallic-mineral studies

Detailed study by T.H. KiiIsgaard of the surface
and subsurface geology at the Samrah silver mine (lo-
cality 1, index map) showed that the ore body is lo-
cated along one of several major silicified breccia zones
where the zone is joined by an east-southeast-trending
set of shears. The ore is along steeply dipping shears and fracture zones in a heterogeneous assem-
bage of rocks ranging from gabbro to granite. The Samrah
vein zone is known to be mineralized for a length of at
least 400 m, and a depth of 220 m. Ore minerals are
spohalerite, galena, pyrargyrite, and tetrahedrite. Drill-
ing indicates about 204,000 metric tons of ore worth
$67 per metric ton.

The Wadi Bidah district (loc. 2) is in an area of an-
cient mines and mineral prospects in the Red Sea es-
carpment region where recent study by R. L. Earhart
shows that massive to richly disseminated deposits of
sulfides in metavolcanic rocks total approximately 2.5
million tons of copper and recoverable zinc, gold, and
silver. The ore minerals are chalcopyrite with sphaler-
ite. Investigation of additional areas may add substan-
tial reserves.

A. E. Weissenborn and R. L. Earhart have conclud-
ed that the Wadi Wassat and Wadi Adhbat (loc. 3)
massive sulfide deposits must be considered pyrite de-
posits only, though they are of the type that elsewhere
in the world contains valuable concentration of base
and precious metals. Assays and analyses are consist-
tently very low in base and precious metals. At Wadi
Wassat the gossans crop out over a strike length of at
least 12 km, more or less confined to a bedded pyroclas-
tic and interlayered andesite unit, and the gossans to-
gether with the underlying sulfides are spatially relat-
ed to transition zones in the volcanic strata. The Wadi Adhbat gossans occur in a similar geologic setting. The pyrite apparently was deposited penecontemporaneously with the pyroclastic material, and was later remobilized by hydrothermal action related to granites and diorite. The Wadi Wasat gossans probably formed initially on an old erosion surface prior to deposition of the Permian Wajid Sandstone. Subsequent erosion of the Wajid Sandstone has again exposed the gossans and cut below the old pre-Permian erosion surface with concomitant downward growth of the gossan. The available drill data are interpreted by Weisborn and Earhart to indicate 84,000,000 tons of 80 percent iron sulfide in the drilled part of the deposit. Much larger tonnages of lower grade material are present in the drilled area; beyond that area, large but unstudied tonnages of massive and disseminated pyrite are present.

Nonmetallic-mineral studies

The phosphate bed at the top of the Cretaceous Aruma Formation, Thaniyat area, (loc. 4) was reported by C. R. Meissner to crop out over a distance of 50 km in an east-trending bluff forming the southwest rim of the Sirhan-Turaif basin. Channel samples analyzed by the Tennessee Valley Authority show the phosphorite to beapatite pellets mixed with quartz sand and clay. The pellets contain 28.2 percent P$_2$O$_5$ and can probably be separated and concentrated by simple beneficiation processes or used directly as electric-furnace feed. An estimated 28 million tons of P$_2$O$_5$ is present in 100 million tons of ore.

At Turaif, 250 km north-northeast of Thaniyat, phosphate is widespread in three zones in the Hibr Formation (Tertiary) in an area of 1,050 sq km. The upper (main) phosphatic zone averages 5.7 m in thickness and contains 7 percent P$_2$O$_5$, including barren bids. Core drilling in the best area indicates 85 million tons of P$_2$O$_5$. This zone is overlain by an average of 15.6 m of chert and limestone, and the phosphate rock is generally hard and calcareous. Calcining, screening, and washing to eliminate the lime would be costly, if water were available.

Reconnaissance for sulfur along the Red Sea coastal plain north of Jiddah revealed only three localities of elemental sulfur. All are in Miocene rocks, are very low grade of no commercial value, and occur where the sequence is thin and only a short distance above basement. In contrast, the vast quantity of H$_2$S in the large oil fields of northeast Saudi Arabia probably was generated by reaction of petroleum with the Hith Anhydrite, but the H$_2$S was unable to escape, and thus never was oxidized to elemental sulfur.

Geophysical investigations

The major sets of linear magnetic anomalies, or magnetic linears, in Saudi Arabia were described by G. D. Andreason as being tens to hundreds of kilometers long and trending north-northwest, parallel and adjacent to the Red Sea Rift. Next most common are north-trending linears, followed by west-trending and northeast-trending linears. The north-northwest and north-trending magnetic linears most commonly are expressed by negative anomalies that range in amplitude between 3,000 and 5,000 gammas on the southwest side of the linear, and positive anomalies that range in amplitude between 1,000 and 2,000 gammas on the northeast side of the linear.

The west-trending magnetic linears also are expressed by negative and positive anomalies having amplitudes ranging between 1,000 and 3,000 gammas. The distribution of anomalies along the linear trend is what might be expected from a steeply dipping tabular feature polarized by induction in the earth's present magnetic field at this magnetic latitude. Northeastly magnetic trends are subtly exhibited by offsetting of magnetic contours.

In the northwest part of the Arabian shield, the azimuths of the major magnetic linears differ from the azimuths of the major mapped faults by 10° to 25°. The west-northwest-trending mapped faults and magnetic linears are along strike of the Najd wrench fault and probably represent feathering faults along this major structural element. The north-northwest-trending structural lineaments, inferred from the major magnetic linears, are later structural features superimposed on this area, probably during and after Tertiary rift faulting.

The predominantly negative magnetic linears occur along major fault zones; thus, possibly the preexisting magnetic minerals in the country rock have been altered to nonmagnetic assemblages by hydrothermal solutions circulating through sheared and brecciated rock in fault zones. Some of these zones have been recognized in the field as sericite-chlorite schist belts. The predominantly positive magnetic linears probably occur along major fault zones which have been filled, at least in part, with igneous material having a higher magnetic susceptibility than the adjacent country rock. Interpretation of the aeromagnetic data suggests that the inferred faults extend from the bedrock surface to considerable depths, that the north-northwest-trending faults may dip steeply to the southwest, and that the west-trending faults may dip vertically to steeply north or south. The major wrench-fault zones are schistose and talcose and may have been too impermeable to have been the channelways for postdeformation m-
alizing solutions. Tension faults on the flanks of the larger wrench-fault zones apparently were open. Many of these tension faults are the loci of mineralization.

Beach sands from the Gulf of Aqaba to Jizan, surveyed by the spectrometer technique, are reported by V. J. Flanigan to have slightly anomalous uranium and thorium activity, but economic concentrations were not indicated. Surveys over pediment areas and Paleozoic sedimentary rocks detected several relative highs for uranium and thorium activity in the phosphate areas at Turaif and Thaniyat Turaiif.

**Geochronology**

The major plutonic events recorded in the Precambrian rocks on the east flank of the Red Sea are interpreted by G. F. Brown to have occurred about 1,000 m.y. ago, on the basis of Rb/Sr isotopic dating. These results are tentative because the older rocks constitute a rubidium-poor and strontium-rich province. The last major plutonic event, most likely to be equated to the Soviet Balkanian or Assyntian orogenic period, resulted in widespread loss of argon from the older rocks. As no later major intrusive epoch is known in Arabia, most K/Ar age determinations probably reflect this episode.

**TURKEY**

**Mineral resources**

The U.S. Geological Survey and the Maden Tectik ve Arama Enstitüsü (MTA) of Turkey began a cooperative study of selected iron-bearing areas as part of a larger program of mineral exploration in March 1968. Contact-metasomatic iron deposits were studied in the Egrigöz Mountains by P. J. Barosh, and in the Şamlı area, western Turkey, by G. W. Leo. Hydrothermal deposits were studied by H. S. Jacobson and R. D. Krushensky at Eymir in western Turkey and by Jacobson near Hekimhan in central Turkey.

Iron deposits in the Egrigöz area (locality 1, index map) consist of magnetite and are restricted to contacts between lenses of regionally metamorphosed marble and a granitic batholith. Individual bodies are small and irregular, and the only one of possible economic significance, discovered by MTA drilling at Çatak, has a high sulfur content. Contact-metasomatic deposits in the Şamlı area (loc. 2) are numerous but small. They consist chiefly of magnetite and are related to contacts between a Permian(?)-limestone thrust plate and an intrusive metadiorite, and to contacts between a younger granite and the limestone and diabase. Where intruded by the granite, the diabase is metamorphosed to a calc-silicate hornfels and skarn. Much of the magnetite in the area occurs as segregations deposited parallel to primary layering, schistosity, fractures, and invading quartz diorite sills. Accessible resources are limited in economic potential by copper, sulfur, and silica impurities. A potentially larger deposit discovered by MTA drilling in the Şamlı area lies under some 300 m of cover, and must be considered only as a latent resource at the present time.

The hydrothermal deposits at Eymir and at Karakuz appear to show the greatest economic potential of the deposits studied. The Eymir deposit (near the Şamlı area) consists of a breccia of silicified quartz dacite fragments in a hematized matrix and massive bodies of hematite replacing quartz dacite tuff and lava. The hematite may have been derived from iron originally present in mafic minerals in the quartz dacite and an underlying andesite. Resources at Eymir total about 20 million tons, most of which requires some form of beneficiation.

Study of the Karakuz mine and surrounding area near Hekimhan (loc. 3) indicates intrusion of an elongate syenite(?)-stock with consequent fracturing and silicification of trachytic country rock, and scapolitization of mafic country rocks. Hematite and magnetite occur in the trachyte as massive and irregular replacements surrounded by aureoles of partially hematized fractures extending into the scapolitized mafic country rock. Resources at Karadug are estimated at about 10 million tons, of which perhaps 10 percent is directly shippable ore.

Regional mapping by R. D. Krushensky in the Eymir area shows base metals irregularly distributed along faults cutting a contact aureole in sandstone. Visible native gold has been seen in a welded ash flow, but the extent of the deposit is unknown.

**Disaster studies**

An earthquake on September 3, 1968, centered in the Black Sea north of Bartin (loc. 4), was briefly investigated by J. P. Albers (USGS) and A. Kalafatçioğlu (MTA). The earthquake had a Richter magnitude of 6.5 to 6.7 and caused severe structural damage to towns and villages east and northeast of Bartin. The principal geologic effect was a 30- to 35-cm uplift of the coastline at the village of Çakraz. Conspicuous surface cracks were formed in alluvium along a river valley, but no bedrock fractures were seen.
ANTARCTICA

Geologic field studies in Antarctica by U.S. Geological Survey personnel were made by P. L. Williams and Irving Friedman during the 1968-69 austral season. Williams, as a United States exchange scientist, accompanied the British Antarctic Survey on summer operations in the Antarctic Peninsula (see index map). His geologic observations and exchange of information with the British as well as geologic field studies, where logistically feasible in the Peninsula, are in accordance with recommendations of the Scientific Committee on Antarctic Research (SCAR) for international cooperation and exchange of scientific information. Friedman, in cooperation with the Institute of Nuclear Sciences, Department of Scientific and Industrial Research, New Zealand, collected material for an isotopic study of the origin of salts and heat in Lake Vanda—a stratified saline, warm lake in the dry valleys area of McMurdo Sound. These activities, as well as geological, geophysical, and paleontological studies in the laboratories and offices of the U.S. Geological Survey, are part of the U.S. Antarctic Research Program sponsored by the U.S. National Science Foundation and logistically supported by the U.S. Navy Operation Deep Freeze. Antarctic base maps and aerial photography are responsibilities of the Topographic Division of the Geological Survey, and progress is reported in the section “Mapping in Antarctica.” (p. A224).

Transposition of the Ellsworth Mountains

Studies of fossil plants from the two areas in Antarctica where Permian beds are folded led J. M. Schofield to consider the general paleogeographic relationships of the Antarctic continent. One of these areas, the Ellsworth Mountains that now occupy an isolated position in West Antarctica, may have originated at the margin of the Antarctic Shield, later to be moved and rotated in response to crustal disruption related to movement on the South Atlantic midoceanic ridge. Unique stratigraphic and structural features of the Ellsworth Mountains are explained by this hypothesis (p. 206). Other “islands” of West Antarctica may have had an origin quite different from that of the Ellsworths, and the Transantarctic Mountains (which form the margin of the shield area) may be an ancient feature parallel to the edge of an old Gondwana rift. The simpler, smaller, and more condensed arrangement of Paleozoic Gondwanaland suggested by this hypothesis, seems consistent with the evidence of trends in Permian climate and general distribution of the Glossopteris flora.

Deception Island eruption of February 21, 1969

A volcanic eruption occurred in the morning of February 21 on Deception Island, a late Quaternary, ring-shaped island that is 10 km in diameter and has a central caldera open to the sea. P. L. Williams visited Deception Island on January 28–29, before the eruption, and after the eruption on March 12–14. The eruption was preceded by earth tremors which began on February 14, and increased in intensity until the morning of the 21st when volcanic activity began as a cloud of steam rising to about 3,000 m. Ash, pumice, and scoria were then ejected from a fissure about 4 km long and 120 m wide, trending about N. 25° W. in the eastern part of the island. The ejecta and gases were erupted through the permanent icecap, several hundred meters thick, that crowns the mountainous island. Several hundred thousand cubic meters of bombs and blocks as much as 3 m in maximum dimension were discharged and came to rest adjacent to the vent near its northern extremity; elsewhere only ash and scoria appear to have been erupted.

Although the eruption was minor in duration and amount of ejecta, it resulted in total destruction of the Chilean base previously damaged and abandoned in the 1967 eruption, and also in partial destruction and abandonment of the British base. Both base facilities were built on alluvial slopes near sea level on the shores of protected bays, less than 1 km from the fissure. Eruption of hot gases and ejecta through the ice cap produced floods of melt water charged with ice blocks and ash which rushed downslope and damaged...
or destroyed the buildings in its path, fortunately without loss of life or serious injury to personnel at the British base, who were heroically evacuated by helicopters from the Chilean naval vessel Piloto Pardo.

The results of the eruption emphasize the danger of establishing permanent bases on alluvial slopes at the base of ice-covered active or apparently dormant volcanic mountains. Flood damage could be avoided or minimized by constructing bases on rocky promontories.

**Late Tertiary glaciation of Antarctica**

The large volcanic islands and peninsulas of the northwestern part of the Ross Sea have been found by W. B. Hamilton to consist largely of ice-contact breccias of basaltic and trachytic compositions. The piles are minimized by constructing bases on rocky promontories. Flood damage could be avoided or minimized by constructing bases on rocky promontories.

**Chemical trends in the Mesozoic Dufek intrusion, Pensacola Mountains**

Chemical trends in the stratiform Dufek intrusion broadly parallel those of the Skaergaard, in Greenland, and other highly differentiated mafic intrusions. Important differences exist, however, probably owing in large part to differences in parental magma according to A.B. Ford.9 Primary structural features indicate that the basaltic magma was periodically stirred by convection during cooling. Textures clearly show that crystal settling was an important process, and that the rocks therefore are "crystal cumulates." The layered series is composed of interlayered cumulate rocks in major “meter-scale” layers: (1) magnetite-clinopyroxene-labradorite cumulates, making up the main bulk of the body; (2) bytownite cumulates, forming the lowest exposed layers; (3) pyroxene cumulates, forming several interlayers in the lower 2 km of the section; and (4) labradorite cumulates, forming numerous interlayers in the upper 2 km of the section. The capping granophyre layer shows no evidence of crystal settling.

Major oxide analyses of all major lithologies through the entire layered sequence are now completed by U.S. Geological Survey analysts under direction of Leonard Shapiro. Minor elements were determined spectrographically by Chris Heropoulos and R. E. Mays. Many major and minor elements are found by A. B. Ford to define two distinct differentiation trends through a large part of the stratigraphic column: (1) a “normal” gabbro trend for the dominant magnetite-clinopyroxene-labradorite cumulates; and (2) a “leucocratic” rock trend for interlayers of plagioclase cumulates.

Structural interpretation by Ford and W. V. Boyd, Jr. (1958), suggests the intrusion is a sheetlike mass at least 6 or 7 km thick; and that the nearly 2-km-thick section in the northwestern Pensacola Mountains forms its lower part, and the equally thick section of the northwestern Pensacola Mountains forms its upper part—the two parts separated from each other by 2- to 3-km of ice-covered rocks in the valley between. Pronounced offsets in chemical variation curves support the interpretation that the layered rocks of the two ranges belong to a single body.

A plot of the mafic index against height shows clearly the overall trend of iron enrichment relative to magnesium during differentiation. Mafic index is not, however, a simple linear function of height, for S-shaped trends appear superimposed on the general trend, which may be due to variations in maintenance of crystal-liquid equilibrium during consolidation.

A plot of silica against height shows a slight negative slope for “normal” rocks through much of the body to about the 5,900-m level where a marked increase occurs leading into the granophyre layer. Bifurcation of the “normal” and “leucox” trends near the top of the Dufek section correlates approximately with the entry of magnetite as a cumulus phase in gabbroic rocks. Silica variation is obviously a much less critical index of differentiation stage than other parameters such as the mafic index.

**Triassic quartz diabase and Triassic (?) orogeny, Pensacola Mountains**

Traditionally, wherever sheets of diabase are found in widespread ranges of the Transantarctic Mountains, they are referred to the "Ferrar Dolerites" of South Victoria Land, where they are locally well dated as Jurassic, probably Middle Jurassic. Most commonly
these sheets are sills in flat-lying Paleozoic to early Mesozoic sedimentary beds. Two sheets of Ferrar-like quartz diabase in the southernmost Pensacola Mountains were mapped and sampled by D. L. Schmidt, A. B. Ford, and R. D. Brown, Jr. Potassium-argon analyses by R. W. Kistler of quartz basalt samples from chill zones yield dates of early Late Triassic, and thus extend considerably the known range of Mesozoic Antarctic diabase intrusions. Some of these sheets therefore may compare more closely with South African Karroo intrusions than formerly believed.

Postorogenic quartz basalt and quartz diabase in thin dikes in the northern part of the Neptune Range cut strongly folded Paleozoic sedimentary beds, deformed in latest Permian or later time. The dikes compare closely in petrology and chemistry with the Late Triassic sills, and thus, according to A. B. Ford, they likely provide a minimum age for a major episode of orogeny. Major Triassic (?) orogeny in the Pensacola Mountains and probably elsewhere around the rim of the Ross orogeny which is recognized throughout a 3,500-km length of the Transantarctic Mountains.

Precambrian eugeosynclinal spilitic and keratophyric rocks, Pensacola Mountains

A large volume of spilitic basalt flows and pillow lavas and a relatively small volume of quartz-keratophyric tuffs and volcanic breccia in the Pensacola Mountains were deposited with interbedded subgraywacke and shale of the Patuxent Formation in a major Precambrian eugeosyncline. A large volume of altered diabase was penecontemporaneously intruded into these rocks. The eugeosynclinal rocks were repeatedly folded during three subsequent orogenies and were regionally thermally metamorphosed to chlorite grade; the shale at best became slate.

Study of the diabasic rocks by W. W. Boyd, Jr., suggests that they also belong to the spilitic suite, but no distinction has yet been made between a primary (spilitic) and a metamorphic origin. Phenocrysts of the fine-grained sill margins consist of abundant altered plagioclase (An_{15-25}), less abundant augite, and chlorite pseudomorphs after olivine. The differentiated coarse-grained interiors of thick sills consist of plagioclase (An_{15-25}), augite, and titaniferous magnetite; the augite (Mg:Fe:Ca = 45:19:36) is slightly altered to actinolite and chlorite and the magnetite is commonly altered to ilmenite, sphene, and rutile (or anatase) or ilmenite and maghemite. The groundmass of the interior rock consists of chlorite, epidote, and microperthitic quartz and alkali feldspar with small apatite prisms. CIPW norms plotted in the synthetic anorthite-quartz-foresterite-diopside system suggest that the least altered fine-grained margin rocks straddle the
anorthite-enstatite-diopside join. This join is a thermal divide at pressures greater than 8 kb and suggests that the magma came from shallow depth. Differentiation within the sills seems to be controlled chiefly by fractionation of olivine and orthopyroxene.

The well-indurated pyroclastic quartz-keratophyric rocks have been dated by the Rb-Sr whole-rock method by Gunter Faure, R. Eastin, and C. H. Shultz at Ohio State University. Four dates suggest an isochron age of 953 ± 175 m.y. (r2451). Two dates suggest that some of the rocks lost their Sr$^{87}$ about 540 m.y. ago, a time that corresponds approximately to a major Late Cambrian orogeny in the Pensacola Mountains and elsewhere in the Transantarctic Mountains.
TOPOGRAPHIC SURVEYS AND MAPPING

PROGRAM MANAGEMENT

Federal mapping coordination

To implement the topographic mapping provisions of the U.S. Bureau of the Budget revised Circular A-16, the U.S. Geological Survey has appointed a Coordinator of Federal Mapping. His duties are to explore the problems related to more effective and continuing coordination of Federal surveying and mapping activities and to develop mutually acceptable approaches toward establishing the standards, procedures, and interagency agreements needed to permit the Geological Survey to carry out its coordination responsibilities.

A study was undertaken to determine how the functions performed by various planning agencies concerned with the problems of metropolitan areas can be better served by maps or related cartographic data. The District of Columbia was selected as the pilot city for this study, and officials of 18 of its map-using agencies have been interviewed. The findings will be sent to selected cities, and officials of these cities will be interviewed to determine whether and how their mapping needs differ from those of the District of Columbia. This study is significant in mapping coordination because Federal agencies are sponsoring many programs that are aimed at alleviating the problems of the cities. These programs are supported by Federal grants that are often used to acquire mapping for planning purposes.

Several of the objectives of the Bureau of the Budget directive are currently being accomplished by the Geological Survey. Many Federal agencies are responding to the Survey's annual request for their topographic mapping needs. Several agencies have contributed information needed for the preparation of the National Atlas of the United States. The Map Information Office of the Geological Survey is collecting and disseminating information concerning aerial photography, topographic mapping, and surveying data that can be made available from Federal agencies.

Program analysis

The Topographic Division contract with the System Development Corp. for a comprehensive program review was completed in 1968. In the study, methods for technological, economic, and socioeconomic forecasts were developed to analyze the future environment of the National Topographic Program. The effects of present value and discounting of costs and benefits on that environment were examined. Demands for topographic mapping were identified in categories of base demand, time-related demand, and derived demand. Identified economic benefit was shown as resulting from several component benefit sources—base value, Federal use, general economic growth, identified projects or activities, and random demand. A cost-benefit methodology was recommended for resource allocation among new mapping, normal revision, interim revision, and special mapping. The study also analyzed the financial aspects of the National Topographic Program, considering appropriated, cooperative, repay, and other funding.

As a result of the System Development Corp. analysis of the National Topographic Program, a planning tool that has great promise has been furnished to the Geological Survey. Completion of the study represents an important first step toward improving understanding of the structure of national map needs and the value of a well-designed mapping program in the economy of a growing nation.

Automation in program management

Work continued on installing segments of the comprehensive topographic program management system while research continued on the overall system. Adjustments were made to accommodate new operating systems introduced for the IBM 360/65 computer and teleprocessing network, primarily to accommodate operation by the central processor on multiple programs simultaneously.

The design of an automated program data bank system to coordinate component files with one another by computer is well advanced. The system provides for inputting data at one point, for referral of these data to component files by computer program, and for automated support of other systems. Several of the 10 files developed for the management reporting system will interact with the master data bank system. Program data file components pertaining to aerial photography used in mapping, geographic classification of map areas in terms of square miles of area by States, and
percentage of area by counties and congressional districts are nearly complete. Reports can be presented in tabular listing and in graphical formats, such as bar, block, or Gantt charts, curves, or geographical index, either on a 1:4,500,000-scale sectional base map of the United States or on larger scale geographic diagrams.

The new automated accounting and production reporting system, Topographic Resources and Cost Evaluation (TRACE), is being integrated with the program data bank, operating program system, and Geological Survey accounting, personnel, and payroll systems. Costs are accumulated in management centers and are distributed to projects by direct hours of labor. Reports will cover costs, schedules, production, and man-hours. Reports of production and hours of mapping are to be teleprocessed, including computer editing to assure integrity of source data. This is an important control procedure because most significant management reports will be derived from these data.

The work-in-progress segment of the data bank has been automated and is ready to support both the program data bank and the TRACE system.

Another major component of the management system is the Resources Balancing System. In this system as many as 48 discrete operations for each of 6 years are scheduled and semiautomatically balanced with funds and capacity by the linear programing technique. Operating programs will be developed on the basis of projections of work accomplished to date. These reports of accomplishment will be entered by the computer from the TRACE system; the computer will also make the projections. Automation of the derivation of management data, including the effect of program decisions made by management relative to current and new projects, has been designed. Ultimately the balancing procedure will be made automatic, although managers can override any or all of the computer-generated solutions, and several alternative program and budget plans can be readily evaluated by this procedure. Computer reports include forecasts of cost, production, manpower, and schedules expressed in both tabular listing and graphical forms.

A system was designed for entering essential aerial photography data elements into the program data bank and for producing management reports segmented according to such items as contractor, kind of photography and lens, mapping project, and geographic area. The status, cost, and basic specification of aerial photography projects are shown in monthly and annual reports. This system is designed to operate as a component of the program data bank, but it could be operated as a satellite system.

### MAPPING ACCOMPLISHMENT*

**Objectives of the National Topographic Program**

The major function of the Topographic Division of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic 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 basic data needed to inventory, develop, and manage the natural resources of the country. Other functions of the Topographic Division include the production of special maps, and research and development in techniques and instrumentation.

Procedures for obtaining copies of the map products of the Survey are given under “How to Order Publications” in the section “Publications Program” (p. A235).

### Series and scales

All topographic surveys for general-purpose quadrangle mapping, except those in Alaska, conform to standards of accuracy and content required for publication at a scale of 1:24,000. Maps of a few remote areas have been published initially at a scale of 1:62,500. However, the 1:24,000-scale surveys for these areas, in the form of map manuscripts, are available as advance prints and for future publication at the larger scale. Maps of Alaska are published at a scale of 1:63,360, or “inch-to-the-mile.”

### Quadrangle-map coverage of the Nation

General-purpose topographic quadrangle-map coverage at scales of 1:24,000, 1:62,500, 1:63,360 (Alaska), and 1:20,000 (Puerto Rico) is now available for about 80 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands, Guam, and American Samoa. Included in this coverage is about 7 percent of the total area which is now available only as advance prints at these scales.

During fiscal year 1969, 956 maps were published covering previously unmapped areas equivalent to about 2 percent of the area of the 50 States and territories referred to above. In addition, 291 new maps at a scale of 1:24,000, equivalent to about 0.5 percent of the total area, were published to replace 15-minute quadrangle maps (1:62,500-scale) which did not meet present needs. Figure 6 shows the extent and location of the current topographic map coverage.

### Map revision and maintenance

Map revision is necessary to show changes in the terrain and additions of manmade features, such as roads, buildings, and reservoirs. During fiscal year 1969, 496
Figure 8—Status of 7.5- and 15-minute quadrangle mapping.
general-purpose quadrangle maps (including interim revision quadrangles) of the 7½-minute series and 10 quadrangles of the 15-minute series were revised and forwarded for printing. Most of these maps are in urban areas or in States that are completely mapped in the 7½-minute series. About 1,450 maps are currently in the revision program (fig. 7).

Revision methods vary, but usually are a combination of photogrammetric, field, and cartographic procedures designed to update map content and to maintain or improve the original accuracy of the maps.

The interim revision method, which was introduced in fiscal year 1967 and implemented in fiscal years 1968 and 1969, consists of obtaining information from aerial photographs about changes in cultural and planimetric features that have occurred in an area, and printing the new data in purple on the previous edition of the map. This type of revision relies primarily on photointerpretation and involves no fieldwork.

Interim revision is being applied first in the urban and suburban sections of the country where rapid expansion and development have caused many maps to become out of date. As the revision backlog in urban areas is reduced, the interim revision program will be applied to rural areas.

In fiscal year 1969, 1,486 general-purpose quadrangle maps were reprinted to replenish stocks.

1:250,000-scale series

The 48 conterminous States and Hawaii are completely covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service. These maps are being revised and maintained by the Topographic Division, with certain changes and additions to make them more suitable for civil use. The Geological Survey is now replacing its previous reconnaissance series maps for Alaska at 1:250,000 scale with an improved series based on larger scale source material and on photogrammetric compilations. Figure 8 shows revision work in progress on 1:250,000-scale maps.

Figure 8.—Revision of 1:250,000-scale topographic mapping.
State maps

State maps are published at scales of 1:500,000 and 1:1,000,000 for all States except Alaska and Hawaii. State maps of Alaska are published at scales of 1:1,584,000, 1:2,500,000, 1:5,000,000, and 1:12,000,000. A State map of Hawaii is being prepared for publication at 1:500,000 scale.

The series of State maps, compiled according to modern standards, now contains 43 maps covering 47 States and the District of Columbia (fig. 9). All these maps are published in planimetric editions; contour and shaded-relief editions are also available for most of them. Nine of the maps, Arizona, California, Colorado, Illinois, Missouri, New Jersey, New Mexico, Ohio, and Virginia, are being revised. Other States are covered by an earlier series, also shown in figure 9.

Metropolitan-area maps

Composite maps at 1:24,000 scale have been published for the following:

- Albuquerque, N. Mex.
- Anchorage, Alaska
- 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.

Honoolulu, 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)
- Oakland, Calif.
- Peoria, Ill.
- Philadelphia, Pa. (2 sheets)
- Pittsburgh, Pa.
National-park maps

Maps of 42 of the 214 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 the 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 general-purpose quadrangle series. Published maps in the national-park series include:

- Acadia National Park, Maine
- Badlands National Monument, S. Dak.
- Bandelier National Monument, N. Mex.
- Black Canyon of the Gunnison National Monument, Colo.
- Bryce Canyon National Park, Utah
- Carlsbad Caverns National Monument, N. Mex.
- Cedar Breaks National Monument, Utah
- Colonial National Monument (Yorktown Battlefield), 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.
- Grand Teton National Park, Wy.
- Great Sand Dunes National Monument, Colo.
- Great Smoky Mountains National Park, N. C.-Tenn. (2 sheets)
- Great Smoky Mountains National Park and vicinity, N. C.-Tenn.
- 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 Park, Ariz.
- Rocky Mountain National Park, Colo.
- Scotts Bluff National Monument, Nebr.
- Sequoia and Kings Canyon National Parks, Calif.
- Shenandoah National Park, Va. (2 sheets)
- Tacoma, Wash.
- Toledo, Ohio
- Washington, D. C.
- Wilkes-Barre-Pittston, Pa.
- Wilmington, Del.
- Youngstown, Ohio
- Vanderbiltn Mansion National Historic Site, N. Y.
- Vickburg National Military Park, Miss.
- Wind Cave National Park, S. Dak.
- Yellowstone National Park, Wyo.-Mont.-Idaho

The map of the Great Sand Dunes National Monument is being revised.

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). Twenty of the 53 maps required to cover the conterminous United States have been produced. From 1955 to 1959, the U.S. Army Map Service published 27 maps of the conterminous United States and 13 maps of Alaska in a military series at a scale of 1:1,000,000. Eventually this military series will be modified slightly and published in the IMW series (fig. 10).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterey maps; and Canada published the Regina and Ottawa 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 (now TOPOCOM).

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 five new maps: Blue Ridge, Quebec, Lookout Mountain, Des Moines, and Ozark Mountains.

Aerial photography

In fiscal year 1969 the Topographic Division contracted for vertical photography covering approximately 142,000 sq mi in the United States. This total included 134,000 sq mi of 6-inch-focal-length and 8,400 sq mi of 4-inch-focal-length photography.
FIGURE 10.—Status of 1:1,000,000-scale topographic maps.

sq mi of $3\frac{1}{2}$-, $8\frac{1}{4}$-, and 12-inch-focal-length vertical photography. The 6-inch-focal-length coverage included 1,700 sq mi of negative color photography and 3,500 sq mi of high-altitude photography flown at about 40,000 feet with a Learjet aircraft.

**MAPPING IN ANTARCTICA**

The Topographic Division continued to assist the National Science Foundation in its United States Antarctic Research Program by furnishing five field engineers and one aerial photographic specialist for the austral season of 1968–69. The field engineers obtained geodetic field control for the topographic mapping program and were responsible for conducting scientific and engineering surveys in support of other disciplines and activities; the aerial photographic specialist was assigned to photographic-liaison duty with the U.S. Navy.

**Topographic field operations**

K. Eissinger, F. S. Brownworth, K. G. Anderson, R. L. Todd, and C. E. Morrison completed 1,059 miles of primary traverse and 275 miles of secondary traverse in Ellsworth Land. An astronomical station was established in the Jones Mountains by daylight stellar observations, and the traverse radiated from it eastward to Farwell Island and Lepley Nunatak, northwesterly through Thurston Island to the Amundsen Sea, and southwesterly through the Hudson Mountains to Pine Island Glacier. The season’s work will furnish control for nine 1:250,000-scale maps covering approximately 40,600 sq mi.

Survey work performed for other disciplines includ-
ed? (1) reobserving the daylight stellar astronomical position at the South Pole Station, (2) establishing two geodetic azimuths at the South Pole Station—one for the U.S. Weather Bureau observer and one for the U.S. Coast and Geodetic Survey geomagnetism observer, and (3) compiling two large-scale (1 inch = 10 feet) topographic maps (by planetable methods) in the McMurdo Sound area for biological studies.

**Aerial photography**

The U.S. Navy Antarctic Development Squadron Six (VXE-6) obtained aerial photographs for mapping in accordance with U.S. Geological Survey specifications, covering about 50,000 sq mi. The new photographs covered portions of the Antarctic Peninsula and western Alexander Island. Fill lines were flown in Thurston Island, southeastern Ellsworth Land, western Palmer Land, Berkner Island, and along the coast of Coats Land. W. F. Roepher served as the technical adviser on aerial photography and as visual navigator on most of the photographic flights.

**Cartographic activities**

The status of U.S. Geological Survey topographic mapping in Antarctica is shown in figure 11. Thirteen 1:250,000-scale topographic maps were published in shaded-relief editions in fiscal year 1969—nine maps completely covering the Pensacola Mountains and four maps of the area between lat 74° and 76° S. in southern Victoria Land. Mapping at the same scale is in progress for 14 maps in northern Victoria Land and 24 maps in the coastal area of Marie Byrd Land between Cape Colbeck and Bear Island. Three 1:500,000-scale sketch maps were published in shaded-relief editions, covering the coastal areas of Ellsworth Land between Thurston Island and the Lassiter Coast (about 128,000 sq mi of unmapped areas). An Index to Topographic Maps—Antarctica, scale 1:10,000,000, was issued showing all Antarctic maps published by the Geological Survey.

**TRUST TERRITORY MAPPING**

In August 1968 a Memorandum of Understanding between the Trust Territory of the Pacific Islands and the U.S. Geological Survey was signed, which provides for the topographic surveying and mapping of the major islands of the trust territory. The maps will be published at 1:25,000 scale in varying formats with basic contour intervals of 5 and 10 m. Maps will be printed at maximum press size rather than standard 7½-minute format to permit whole islands to be shown on one map and to require as few sheets as possible for the mapping project.

**INTERNATIONAL ASSISTANCE PROGRAMS**

**Saudi Arabia**

The U.S. Geological Survey is continuing to assist the Ministry of Petroleum and Mineral Resources (MPMR) of Saudi Arabia in assessing the mineral potential of the Precambrian shield area of central and western Saudi Arabia. Since the beginning of the program the Topographic Division has had two engineers and a photogrammetric specialist in Saudi Arabia to support these investigations. The party of six field survey specialists sent to Saudi Arabia during 1968 returned to the United States after completing the mapping control for approximately 32 quadrangles in two separate 16-quadrangle projects designated Saudi Arabia Phosphate Areas I and II. The maps are to be compiled and published at a scale of 1:250,000. Phosphate Area I is being completed for publication in Saudi Arabia. Phosphate Area II is being compiled and drafted by the Topographic Division Central Region office in Rolla, Mo. Four of these quadrangles will be completed through publication as pilot orthophotomaps. The remaining 12 will be completed through the cartographic stages and returned to Saudi Arabia for publication using the pilot sheets as guides. The quadrangles in area II have been completed through the photogrammetric compilation stages and are awaiting field corrections and name information before proceeding through the cartographic phases. When these orthophotomaps are published, they could set the standard for the national mapping program at 1:250,000 scale in Saudi Arabia.

**Brazil**

The Technical Assistance Loan Agreement, administered by the U.S. Agency for International Development (AID), for mineral and water projects with the Brazilian National Department of Mineral Production and the National Department of Water and Energy (DNAE) of the Ministry of Mines and Energy was approved and signed by the Government of Brazil in 1968. As part of this program, the Photogrammetry Service Project (DNAE-2) is progressing. DNAE-2 is primarily intended to provide advisory and training service to the photogrammetry section in DNAE and to assist in increasing its activities, especially in producing large-scale topographic maps. This assistance will include upgrading certain stereoplotting and interpretation equipment and establishing a cadre of well-trained photogrammetrists. The Topographic Division has promised to furnish technical assistance in the form of several advisory personnel to DNAE's
FIGURE 11.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1969.
photogrammetric service and to train several Brazilian participants in this country.

Liberia

The geological exploration and resources appraisal project in Liberia is a cooperative effort of the Government of Liberia and the U.S. Agency for International Development (AID) under a development loan agreement. The Topographic Division had one cartographic technician in Liberia during fiscal year 1969 to support this program. The Branch of Special Maps is completing 1:40,000-scale form-line maps of selected areas in Liberia. To date 213 of these maps have been completed; 108 during this fiscal year. Although the primary source data for these maps is recent aerial photography, older photography and previous mapping are also used if needed.

International participant training programs

The Topographic Division continues to aid in training principals from other countries in the various phases of mapping operations. During the fiscal year, participants came from Afghanistan, Argentina, Brazil, Guyana, India, and Indonesia. Tours of division mapping facilities and training schedules for all foreign engineers and technicians are arranged by the Branch of International Activities. The branch also aids in the organization of academic programs for foreign participants at universities and colleges in the United States.

NATIONAL ATLAS

The U.S. Geological Survey is continuing its work to prepare and publish a National Atlas to be used as a reliable reference by Congress, government agencies, businesses, industries, libraries, and schools. This 475-page volume will be 19 × 14 inches, with about 30 percent of the maps opening to double-page spreads of 19 × 28 inches.

As of July 1, 1969, all National Atlas maps are either being scribed on color-separation drawings or are in the process of being printed for the bound edition. Sixteen pages for the bound edition have been completed, and 40 pages have been published as individual map sheets for sale to the public.

During the past year, dummy atlases were prepared for testing to determine the best type of binding for books of their size. The tests were completed in July, and final binding specifications are now being prepared.

One million sheets of paper—sheets identical with those used for individual maps—have been obtained for the bound edition through the U.S. Government Printing Office. The rest of the paper for the atlas will be obtained within the next few months.

Over 35,000 map-feature entries for the atlas index have been submitted for machine alphabetizing, to be completed in the next few months. The completed index, which will be in the back pages of the atlas, will contain over 40,000 entries coded to the atlas map showing individual features at the largest scale.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Laser Geodimeter

The laser has been found to be a useful tool in measuring distances in control surveys for topographic mapping. A laser light source has been adapted to the model 4 Geodimeter, an electronic instrument that uses the principle of light-wave propagation for measuring distances. Before this modification, the Geodimeter was used mainly at night because its daylight range was limited by the relatively low intensity of its mercury-arc light source.

The use of the laser light source has increased the range of the modified instrument to about 25 miles at night and nearly 15 miles in daylight—more than double the range of the standard Geodimeter. The resulting increased signal strength gives smaller reading variations and greater accuracy. Preliminary tests over precise taped base lines 1,650 and 9,000 m long have indicated a measuring accuracy of one part per million. The laser-equipped Geodimeter weighs about 6 pounds more than the standard model 4D instrument. It consumes about 30 watts of power, in comparison with 100 watts for the mercury-arc light source. A small motor generator supplies the power.

Portable mast

Masts are useful in control-survey operations to support targets which must be seen above vegetation, hill, or other obstructions. Portable masts for supporting a rotating beacon light and a reflector for use in control-survey operations have been fabricated. The masts, which can be carried by hand, were constructed with square thin-walled steel tubing. When fully extended, one version is 56 feet high and another version is 74 feet high.

The mast is erected by securing its 12- × 12-inch footplate on the ground alongside a station mark, hand-lifting the closed mast to the vertical, and tying a lower set of guy ropes. The mast is raised and lowered mechanically by a hand winch with a system of cables and sheaves. To adequately secure the mast throughout the telescoping process, one section is ex-
tended fully and guyed before the next section is extended. The tubing has a wall thickness of 0.05 inch, with enough spring action for the light to be centered over a station mark by adjusting the tension of the top guy ropes.

The mast's closed length is 21 feet. It may be transported on a truck in the same way as level rods. Total weight of the mast is 115 pounds, including signal light, electric wires, guy ropes, and ground anchors.

**Equipment modifications**

As a result of operational tests of the portable surveying tower, the new truck hoist assemblies have been modified. The hydraulic cylinders were replaced with cylinders capable of developing 6.6 times the force required to lift a 60-foot tower. A new hydraulic control valve was installed which allows smooth lifting and lowering of the tower in all positions. To increase the efficiency of the electric hydraulic pump, two 12-volt batteries were wired to provide 24 volts. The extra battery may be charged by the truck alternator.

About 60 versatile new signal lights have been made and are now in service. The lights can accommodate a wide variety of PAR-36 and PAR-46 sealed-beam lamps, up to a power rating of 500 watts, including a quartz-halogen lamp that delivers 300,000 candlepower at a power drain of only 55 watts. The lamps can be turned on and off at the station by means of a pushbutton switch or a 24-hour, 8-day clock timer, or from a remote station by means of an audio tone generator and standard field radios (T.O. Dando, p. D291–D293).

Recent experiments have been conducted with polarization filters to remotely regulate the intensity of signal lights. A set of linear laminated polarizers is used, one of which snaps on the lampholder at the light source, whereas the other fits over the eyepiece of the theodolite. An adaptor for the eyepiece allows the filter to be rotated without disturbing the crosshair focus of the instrument. Eyepiece filter attachments have been made for Wild T2 and Kern DKM3 theodolites. With the pair of polarizers the attenuation can be changed smoothly so that the observer can select the best target size for pointing. Target identification is also improved with the polarizers.

**Integrated processing of field control data**

New information systems technology will have a major effect on present procedures for handling field control data. Feasibility studies are underway on an integrated data processing (IDP) approach to preparing mapping control data for computer input. The IDP computer system would eliminate a second manual handling of data and possibly preclude any manual data recording; the data would be transcribed once in machine-readable form, and thereafter would be available for all purposes without manual handling.

Special typewriters with machine-readable characters and an optical character reader (OCR) are available for use in the development of the IDP system. Experimental geodetic control lists have been coded with OCR characters for automatic processing jobs, such as metric conversion, without massive manual manipulation of data. In addition, control location descriptions typed in OCR characters are being tested for automatic entry into a storage-and-retrieval system.

**Computer programs for geodetic computations**

The Topographic Division is developing a master geodetic-computations program designed to complete on the IBM 360/65 computer all the computations of a survey network in a series of segmented runs. The main program is written so that a set of subprograms can be selected by the user to perform all the desired computations on field observations, made either for horizontal or vertical control, in traverse or triangulation surveys. At key points in the program, the user can also call for information on closures and blunders, for a least-squares adjustment of data, and finally for a printout record of the results.

A program for plotting control diagrams for mapping projects has been written. The program generates coded instructions on magnetic tape for input to a Gerber 532 plotter. The plotter constructs a geodetic control diagram with geodetic boundaries, latitude and longitude labels, primary- and secondary-station positions and symbols, station names, lines of sight, and project title block.

A program for computing geodetic azimuth from observations on circumpolar stars has been prepared and documented. The program accepts optional input for third- or higher-order accuracy, for observations on several circumpolar stars.

**STARLIST**, a general-purpose program to print a star-finding list, has been developed. By means of this program an observing list can be prepared for any location in the world, for almost any kind of astronomical observation, and for several makes of theodolites.

The program input consists of a card deck containing star number, declination, right ascension, and magnitude for about 1,400 stars from the FK4 catalog produced under the auspices of the International Astronomical Union. Only stars of magnitude 5 or brighter are included. The user sets the parameters for star selection. The computer prints out an observing list for each station with the star number, its magnitude, and...
horizontal-plate and altitude settings for the theodolite in order of increasing local sidereal time. The starker program is currently being used for fieldwork in Micronesia.

**Hydrafracture uplift test**

The Topographic Division in cooperation with Water Resources Division completed precise control surveys for one of two earth hydrafracture tests which were designed to find a safe, efficient procedure for underground disposing of certain types of atomic waste. The first test was conducted in an area surrounding an oil well near Reno, Pa. Liquids were injected under high pressure into the well, which was plugged where it penetrated a selected rock stratum. Before and after the injection, precise control surveys were run to detect earth crustal movements as small as 0.003 foot vertically and about 0.06 foot horizontally.

The Quaker State Refining Co. furnished the well site located on the nose of a ridge extending north from the Allegheny River and directly north of Reno, Pa. Thirty-five bench marks were set by field parties on lines at approximately equiangular intervals extending out as far as 500 feet from the well. Precise level lines run with a Wild N3 level were started from and tied to bench marks located more than a mile away from the site. Horizontal movement was checked with a Geodimeter from two stations also isolated from the site.

The results of the resurveys indicated that the terrain around the site had generally been raised about 0.005 to 0.007 foot and that slight horizontal shifts had occurred (up to 0.4 foot) but in no fixed pattern.

Control surveys will also be run for a similar test at West Valley, N.Y., on the property of the Western New York Nuclear Center.

**PHOTOGRAMMETRY**

**Analytical aerotriangulation**

Analytical aerotriangulation methods continued to be tested and refined with respect to planning of operations, acquisition of data, and computer processing. In addition to the test projects, three production mapping projects have been active this fiscal year.

The Bowling Green, Va., research project, involving aerotriangulation of a block of eleven 7½-minute quadrangles, has been completed by using the fully analytical direct-geodetic-constraint method. The photographic coverage for the project consisted of about 420 exposures obtained in 16 flight lines at a flight height of 9,500 feet. The solutions were constrained to 42 horizontal and 277 vertical control points. All these points, both horizontal and vertical, were targeted for identification on the photographs. The pass points were marked with a point-marking device on all photographs upon which they appeared, and the photo-coordinates were measured on a Nistri monocomparator. The solutions were evaluated by field checks of selected elevations generated by the block adjustment. These elevations were found to meet the standard requirements for supplemental vertical control used in photogrammetric mapping. Stereocompilation is about 95 percent complete and has progressed smoothly, with no significant problems.

In cooperation with the U.S. Coast and Geodetic Survey, a research project is being carried out to evaluate the applicability of the Coast and Geodetic Survey fully analytical block method of aerotriangulation for U.S. Geological Survey topographic mapping, particularly in large uncontrolled areas such as exist in the Western States. The study involves the aerotriangulation of a 30-minute-square area near Tucumcari, N. Mex. Photographic coverage comprises 1:60,000-scale super-wide-angle aerotriangulation photographs and 1:20,000-scale wide-angle compilation photographs. The aerotriangulation solution yielded standard errors of 2.1 feet horizontally and 1.7 feet vertically at targeted test points. Two selected quadrangles are being compiled with the photogrammetric control and will be field tested for compliance with the National Map Accuracy Standards.

A fully analytical aerotriangulation project is planned for a 16-quadrangle block in central Pennsylvania. The photographs have been obtained, and photo-coordinates are being measured on a Nistri stereocomparator equipped with an analog-to-digital readout and recording device.

**Semianalytical aerotriangulation**

Although semianalytical aerotriangulation is now an accepted procedure for adjusting points on aerial photographs for mapping operations, research activities are continuing in an effort to streamline the existing methods and to evaluate them for different applications.

A recently completed research project evaluated the accuracy and economy that can be obtained when small-scale photographs over large areas are adjusted by horizontal semianalytical block methods to provide horizontal photogrammetric control for larger scale compilation photographs. This project differed from other similar projects in that the model control for the mapping photographs was established directly from the small-scale photographs, rather than from a second-generation adjustment with the large-scale photographs. The Wahoo, Nebr., project, consisting of 13
quadrangles, was used for the test. About 30 well-distributed second-order horizontal control points were targeted before the super-wide-angle aerotriangulation photographs (1:69,000 scale) were taken; 40 additional horizontal control points were identified but not targeted. Two second-degree block adjustments, differing only in the amount of perimeter control, were run with the Schut method. When 24 perimeter points (not all targeted) were held, the root-mean-square error (RMSE) at test points was 15.0 feet; when 18 perimeter points (all targeted) were held, the RMSE was reduced slightly to 14.3 feet.

Experiments are being conducted to determine whether three-dimensional semianalytical aerotriangulation, developed from instrumentally bridged strips, is practical even in areas where costs for supplemental control by field methods are relatively low. In one 16-quadrangle project (Medford, Wis.) the strips were bridged on the Wild A7 stereoplotter and adjusted with the Schut strip-and-block method. Fly levels were run to test the vertical accuracy of the adjustment. The experiment indicated that the method was economical and would produce satisfactory results under favorable conditions. A second test, involving the 16-quadrangle Eagle River, Wis., project, is being planned. Photography and field surveys were scheduled for spring 1969.

Research is underway to determine whether, and under what conditions, semianalytical methods can be used successfully for combined horizontal and vertical block adjustments. Two test projects of eight quadrangles each have been aerotriangulated. All ground control for these projects was targeted. Evaluations of the results are still underway; however, preliminary findings appear to be very favorable.

Use of high-altitude photographs in topographic mapping

Aerial photographs taken from high-flying jet aircraft are finding considerable application in topographic mapping operations of the U.S. Geological Survey. These photographs, taken at altitudes up to 40,000 feet, are used to aerotriangulate large unmapped areas, to orient and control mapping photographs taken at lower altitudes, and to produce small-scale orthophotographs which are valuable in revising existing maps. These same orthophotographs, which cover more than 100 sq mi, or about twice the area of a standard 7½-minute quadrangle map, also have the potential of being converted into economical orthophotomaps.

High-altitude photographs have been successfully used for semianalytical aerotriangulation of two large projects to provide model-orientation control for map compilation or to provide control for subsequent block adjustments with lower altitude compilation photographs. In both projects, the only horizontal control points used to constrain the adjustments were those that already existed; that is, no new field control surveys were needed.

The Rocky Point, Ariz., project, consisting of thirty-two 7½-minute quadrangles, was photographed at two scales, 1:32,000 and 1:33,000. The 1:32,000-scale photographs were used for the horizontal adjustment of the entire block and for the vertical adjustment of about half of the project. The 1:33,000-scale photographs were used for a subsequent horizontal and vertical adjustment of the remaining half of the project with additional control provided by the horizontal positions from the high-altitude photographs. The accuracies achieved in the adjustment with the high-altitude photographs were as follows: Horizontal root-mean-square error (RMSE) at 37 held points, 10.6 feet; horizontal RMSE at 31 test points, 9.9 feet; and vertical RMSE at 292 held points, 5.5 feet.

The Alamo, Nev., aerotriangulation project consists of a rectangular block of eighty-four 7½-minute quadrangles, or about 5,200 sq mi. The 1:80,000-scale aerotriangulation photographs were taken in a jet aircraft at a flight height of 40,000 feet in 10 strips containing 170 photographs. Horizontal semianalytical aerotriangulation with the 1:80,000-scale high-altitude photographs, constrained to existing horizontal control lying entirely on the periphery of the area, provided horizontal positions for a subsequent horizontal-and-vertical semianalytical aerotriangulation with the 1:35,000-scale compilation photographs for the authorized mapping area. The results of the horizontal block adjustment with the high-altitude photographs were as follows: Horizontal RMSE at 27 held points, 10.4 feet; and horizontal RMSE at 12 test points, 12.1 feet.

Applications of color aerial photographs

Studies to evaluate the topographic mapping applications of color aerial photographs are continuing. In several projects, side-by-side comparisons are being made of the relative capabilities of Kodak Aero-Neg color photographs and standard black-and-white photographs for compilation and revision.

Field tests have been completed for the Starrucca, Pa., project in which three of the 7½-minute quadrangles were compiled from color photographs while three others were compiled from black-and-white photographs. The vertical accuracy tests produced a mean error of 1.3 feet in quadrangles compiled from color
photographs compared with 1.8 feet mean error on quadrangles compiled from black-and-white photographs. The maximum error on color compilation was found to be 4 feet, while that from black-and-white compilation was 7 feet. It was also found that the planimetry compiled from color photographs was slightly better than that compiled from black-and-white photographs, particularly in the delineation of woodland, shorelines, and swamps. It is planned to follow up this finding by using color photographs for interim revision of a large area in southern Florida where the woodland, swamps, and shorelines are major planimetric features.

Color photographs at 1:30,000 scale have been used as a stereoscopic supplement in the interim revision of two 7 1/2-minute quadrangles in the Seattle, Wash., area. It is noted that color contrasts generally enhance the photointerpretation and delineation of planimetric features and produce a favorable psychological effect on the stereoplotter operator. Specific advantages over black-and-white photographs are found in the classification of buildings in clusters, interpretation of isolated buildings in wooded areas, water-feature classification, and classification of terrain cover. A new mapping project, involving comparisons of black-and-white and color photographs for map compilation in the Crown King, Ariz., 15-minute quadrangle, is planned but not yet underway.

Instrumentation and techniques are being developed for preparing color orthophoto products from color aerial photographs. Experimental color orthophotos have been made and are being evaluated to determine their usefulness in geologic field investigations.

Image correlator

The Bolsey image correlator was given various tests during the past year to assess its utility in data gathering for analytical aerotriangulation. Results of these tests justify further development of the instrument.

In its present form, the correlator scans an annular ring of photoimagery on a diapositive or other photographic record, converts the optical imagery into electrical signals, and stores the scanned scene on a magnetic drum. Once the scene is stored, the correlator can view the same scene from the same or a different perspective point and indicate both the general degree of correlation and the displacements in terms of $x$, $y$, and $\theta$ with an accuracy of a few microns. The present model of the Bolsey image correlator is mounted on a digitized Mann 9-inch monocomparator and has a memory capacity of 8 channels.

A test exercise, designed to evaluate the capability of the instrument to correlate images appearing on adjacent flight strips, for example, to transfer tie points, has been completed. A 14-photo, 2-strip block of 1:48,000-scale glass-plate negatives was aerotriangulated with the Schut fully analytical method. This test was the first attempt to aerotriangulate a block with photocoordinate data derived with the image correlator, and the results were exceptionally good. The root-mean-square error at targeted test points was about 2.0 feet, both horizontally and vertically.

A contract has been let for the construction of a second-generation production version of the correlator. The new model will be equipped with an electronic scanning system and a punched-card memory. The punched cards will provide unlimited storage capacity, simplify the task of signature bookkeeping as transfers are made, and serve in an integrated data processing computer system.

**CARTOGRAPHY**

**Orthophotomapping**

The many advantages and useful applications of uniform-scale photographs have led to rapidly increasing interest in orthophotomaps by map users and a corresponding expansion of the orthophotomapping program by the U.S. Geological Survey. Both experimental and standard editions are being prepared; 25 orthophotomaps have been printed, 37 more are in various phases of production. Many other projects are now in the planning phase, and it is expected that production will begin in fiscal year 1970 on more than 200 new orthophotomaps.

Photograph rendering is suitable for many types of terrain—swamps, shorelines, desert areas, agricultural and grazing lands, and urban areas—but the current trend is toward orthophotomapping of hydrographic features. Sixteen 1:24,000-scale orthophotomaps providing complete coverage of the Georgia-Florida Okefenokee Swamp were published as standard s-les editions. The successful production of a single orthophotomap in the Florida Everglades led to plans for orthophotomap coverage of a large part of the swamp area—more than eighty 7 1/2-minute quadrangles. Other planned orthophotomapping projects in which the principal features are hydrographic include the Great Salt Lake, Utah (41 maps), Wilmington-Snow Marsh, N.C. (14 maps), Slatenville, Ga. (11 maps), and Edisto Island, S.C. (10 maps).

The results of an investigation have shown that orthophotomaps of urban areas are useful for many kinds of urban studies. It was found, however, that orthophotomaps at scales larger than 1:24,000 are needed in metropolitan areas. Experimental orthophotomaps produced for this investigation are the
Washington, D.C., and the Parkersburg, W. Va., 2½-
by 3½-minute quadrangles at 1:7,200 scale and the
Philadelphia, Pa. 3½-minute quadrangle at 1:12,000
scale. Orthophotomaps of Cedar Rapids, Iowa, Seattle,
Wash., and Dallas, Tex., are in various stages of pro-
duction. Another finding of this investigation was that
photographs taken with a camera of 12-inch focal
length, rather than the standard 6-inch camera, pro-
duce better orthophotomaps of urban areas because of
improved image resolution and less displacement of
tall buildings.

The U.S. Geological Survey Orthophotoscope has
been adapted for preparing orthophoto products in
color from color aerial photographs. To evaluate these
new products, a pilot project is underway to determine
their usefulness in geologic field investigations. Sample
color orthophotographs at 1:13,000 scale have been
made for an area of geologic interest near Dillon,
Mont., and the samples have been sent to a field party
in the area.

The current research effort is devoted to (1) devel-
oping equipment and techniques for automating the
Orthophotoscope, (2) preparing aerial photography
specifications for orthophotomapping, and (3) experi-
menting with cartographic techniques, colors, and sym-
bols for portraying features on orthophotomaps.

Automation in cartography

The U.S. Geological Survey and the Experimental
Cartography Unit, Royal College of Art, Oxford,
England, have begun a program of information ex-
change to advance automatic cartography techniques.
Such important subjects as equipment and techniques
for automation, map-feature codes and symbols, gen-
eralization for small-scale mapping, and a geographic
names placement system are being studied. The ex-
change of information has been started through the as-
signment of a Geological Survey engineer on detail to
the Royal College for 8 weeks. It will continue in the
exchange of digitized magnetic tapes and through joint authorship of papers.

Preliminary work has begun toward merging the
technology of high-speed electronic computers with the
cartographic phase of the National Topographic Pro-
gram. The plan is called geoscat for Geological Sur-
vey Cartographic Assistance Technique. The lines and
symbols of a map would be digitized to create a graph-
ic file. When this information is read into the comput-
er memory, it can then be displayed on a cathode-ray
tube (CRT) console. In this form, by using a light pen
on the face of the CRT, the operator can change the
graphic file in the computer memory. Also, new map
information digitized directly from stereoscopic mod-
els could be transformed by means of a common coor-
dinate system, read into the computer memory, and
then displayed in correct absolute position together with
previously processed map information. This proj-
ect in computer graphics will be developed in coopera-
tion with the Washington Scientific Center of Interna-
tional Business Machines Corp.

An automatic line follower is being develop-ed to
tsrib color-separation drawings from compiled manu-
scripts, to digitize lines, and to follow profile lines. It
consists of a light table, a modified precision coordina-
tograph, an optical head, electronic equipment, and
servomotors for driving the optical head. The optical
head follows penciled, inked, or printed lines along a
simple or complex path with hairpin turns, circles, or
right angles. The scribing head, mechanically coupled
to the optical head, duplicates the path of the optical
head. The prototype machine, in its present form, will
not operate without occasional manual assistance, and
therefore several changes in the design are being made.
The reliability of the electronic circuitry has been im-
proved, and a new optical head has been designed to
increase stability and reduce electronic noise. Encod-
ers and readout equipment have been added to the line fol-
lower for storing linear map data in digital form. A
modified version of the instrument is being built for
following profiles obtained by analog means from a
stereoscopic model. This capability is intended to be
used to automatically drive the z axis of the Orthopho-
toscope during the exposure of the orthonegative.
Although hardware acquisitions in fiscal year 1969 were small, contrasted to those of the preceding year, the U.S. Geological Survey computer center was actively engaged in the area of systems and applications programming. The year was spent in improving the operating efficiency of the equipment at hand and finding new ways to use it.

The major hardware acquisition was a Calcomp drum plotter, installed at the computer center in Washington, to be used to plot the locations of water-data gathering sites and to indicate the kind of information available at each site. The plotter will also be used for other applications of general nature.

Several software acquisitions made during the year include the WATFOR FORTRAN compiler, the LDR fast-linkage loader, the Query report generator program, the University of Oklahoma Gipsy program, the University of California at Los Angeles (UCLA) biomedical statistical program package, and the FOR-MAC system.

**Systems support**

The WATFOR FORTRAN compiler and the LDR fast-linkage loader were bought to improve the operating efficiency of the U.S. Geological Survey computer and to provide better service. WATFOR is a FORTRAN compiler developed at the University of Waterloo, Ontario, Canada. It was developed with two main purposes in mind: (1) to provide better error diagnostic messages to enable the programmer to locate and correct his mistakes, and (2) to use the least amount of computer time possible in compiling the program. It succeeds admirably in both respects. It checks the program thoroughly for errors, gives the programmer clear and concise messages about any errors it finds, and then compiles the program at speeds ranging from 10 to 30 times faster than the standard IBM compiler.

This compiling speed is important, inasmuch as roughly 75 percent of our programs are written in FORTRAN, and about 50 percent of our total workload is compiling programs. By using WATFOR, significant savings in computer time can be realized.

The second set of programs, called LDR, is designed to replace the standard IBM linkage editor. Its function is to load the compiled program, the data, and any library routines needed into the computer for execution. With the standard editor, as much as one-third of the total processing time can be consumed by this nonproductive activity. With LDR, however, the time spent loading the program can be cut by as much as 50 percent, making more time available for other, more productive work.

The implementation of these two programs is part of the overall effort in the Geological Survey computer center to run the computer at its maximum efficiency.

**Applications support**

While improvements in efficiency are important, of even greater long-range benefit is the work being done in the area of applications-related programming. Even though most of this type of work is done in the Geological Survey computer center at the request of the Survey operating divisions, some additional work is being carried on independently as a general support activity. The Query report generator program, the University of Oklahoma Gipsy program, the UCLA biomedical statistical program package, and the FOR-MAC system mentioned above fall in this applications support category.

The Query and Gipsy programs are representative of an approach that is growing in use and importance in computer work. Previously, a person who wanted to use a computer either had to learn a specialized programming language or had to explain his problem to a programmer who would write the problem in a programming language. Now the trend is to put the ultimate user and the computer in direct contact. There are two basic ways to do this. The first way, called time sharing, will be discussed later. The second way is to use a user-oriented translator to accept instructions from the user and pass these along to the computer in language it can understand.

Query and Gipsy both attempt to bridge this man-machine gap. The Query program can be used with predominantly numerical data files to produce reports and tabulations on a demand basis. The ultimate user of the data can be taught to use Query in a matter of a few hours. In a few minutes he can formulate a report request that would take days to write in conventional programming languages. Gipsy is useful for textual material where it is desirable to search for and extract in-
formation from the file in a way that was not necessarily anticipated or planned for in advance.

The UCLA biomedical package has been installed on the Geological Survey computer to make its extensive statistical facilities available. This will supplement our own existing library programs and those supplied by IBM. With all these programs on call, the need to write individual programs will decrease, and the ability to quickly and easily process data and obtain the required results will be enhanced.

FORMAC is an IBM-supplied program that translates a formula, expressed in mathematical terms, into a programming language. Even though its use is still being tested, it seems to hold promise for cutting down the amount of programming required in mathematical problem solving.

Applications programming

Besides the acquisition and implementation of software packages, some significant applications-related programming has been done by the staff of the computer center. Three of these projects are mentioned here: two having to do with plotters, and one concerning satellite photography.

Much of the work of the Geological Survey is graphical in nature. For this reason, plotters are used extensively in Washington and in the field centers. To provide the data needed to drive these field plotters, telecommunications are used. By standard techniques, the data are transmitted to the remote terminal, punched into cards, and the data then transcribed from the cards to magnetic tape. This technique is both costly and slow. To overcome these objections a new technique was developed which bypasses the intermediate card-punching step and records the data directly on tape. This improved technique has been used successfully to improve service for the Topographic Division's Autoplot system, as well as for the general-purpose plotter in the Menlo Park, Calif., center.

A second project has resulted in the capability to produce three-dimensional plots. This means that an ordinary plotter, drawing on flat paper, can produce a drawing that will appear to be three dimensional. This has obvious application in structural geologic studies, molecular and crystal structure research, and civil engineering, among others.

The use of satellites for high-altitude aerial photography is increasing, both for military and civilian purposes. The Geological Survey has been working in this area, and will expand its activities with the advent of the EROS satellite. Some preliminary programming has been done to process the data sent back, convert it into representations of various types of terrain, filter out noise, and enhance and print the image.

To improve the distribution of information on computer-related work done by the Geological Survey, and to make this information available more quickly, a new series of open-file reports has been established. Called U.S. Geological Survey Computer Contributions, this new series will be available on request in advance of formal publication of the information.

Time sharing

When computers first came into use a few years ago in the "first generation," it was not uncommon for each user to have the entire computer at his disposal for an allotted period of time. This made it easier for the user to test his program, since he was not contending with anyone else for the system. He could get first response and make several test runs within his allotted time.

The second generation of computers saw a number of changes, among them the institution of batch processing, in which a program was batched with others and run as part of a series of runs under the control of a monitor program. This was an improvement in efficiency, since much setup and idle time of the first-generation procedure was eliminated. However, it was at the cost of loss of responsiveness that this gain in efficiency was achieved. Each programmer had to wait for all the jobs in the batch to be run before he could get the results of his own program.

With the advent of the third generation of computers, an effort was made to combine the best features of both previous procedures. The result is a computer that is under the control of an operating system—an extension of the second generation monitor—and can provide both batch processing and time sharing.

Time sharing gives the user the direct access to the system, the fast response, and the ability to run his program several times in a short length of time—advantages he enjoyed on the first-generation machines—but with the improved operating efficiency of the second generation. When coupled with simplified programming languages or user-oriented programs like Query or Gipsy, the time-shared computer can become a useful tool for many people who have never been able to use computers before.

The U.S. Geological Survey computer center began a program of time-sharing in 1969, and will continue and expand it in 1970. Several offices are interested in using a time-sharing system for such activities as accounting and personnel-data processing, text preparation, literature searching, report generation, and management information display. As the uses for, and the volume of use of, time sharing grows, the computer center will provide its own time-sharing system to replace most of the outside contracts.

Note.—For discussion of specific applications of computer technology to various subject-matter fields see sections listed under "Computer technology" in the subject index.
PUBLICATIONS PROGRAM

Results of research and investigations by the U.S. Geological Survey are made available to the public through various reports and maps, most of which are published by the Survey. Of the formal reports published by the Survey, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Survey.

All books, maps (exclusive of topographic quadrangle maps), and related publications published by the Geological Survey are listed in "Publications of the Geological Survey, 1879-1961," and in yearly supplements that keep the catalog up to date. New publications are announced each month in "New Publications of the Geological Survey." All these lists of publications are free upon request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Books, maps, charts, folios, and atlases that are out of print can no longer be purchased from any official source. They may be consulted at many libraries, and some can be purchased from dealers in secondhand books.

PUBLICATIONS ISSUED

During fiscal year 1969, 242 technical book publications were published (237 in fiscal year 1968). The number of maps printed was 4,041 (4,361 in fiscal year 1968), comprising some 15,345,000 copies (19,098,000 copies in 1968).

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In addition, the Geological Survey printed 1,724 leaflets and maps of flood-prone areas.

Geological Survey maps are distributed by mail from bulk stocks at Arlington, Va., Denver, Colo., and Fairbanks, Alaska. Over-the-counter distribution of maps is made by these and 12 other Survey offices.

In addition to 74,450,000 maps and books on hand at the beginning of the year, 13,961,800 copies of new and reprinted maps and 1,815,100 copies of books (including popular-information booklets) were received into the Survey's distribution system. A total of 5,933,500 copies of maps were distributed, including 546,100 index maps. Approximately 4.8 million copies of maps were sold, and $1,712,224.85 was deposited to miscellaneous receipts in the U.S. Treasury ($1,558,969.66 in fiscal year 1968).

Also during the fiscal year, the Geological Survey distributed 424,167 technical book reports, without charge and for official use, and 2,125,144 booklets, free of charge, chiefly to the general public. In addition, 179,500 copies of the monthly publications announcement and 250,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution was implemented by 455,700 individual orders. The following table compares Geological Survey map and book distribution (including booklets but excluding monthly announcements and symbol sheets) during fiscal years 1968 and 1969:

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HOW TO ORDER PUBLICATIONS

Ordering book reports

Professional papers, bulletins, water-supply papers, "Geophysical Abstracts," "Topographic Instructions," "Techniques of Water Resources Investigations," "Abstracts of North American Geology," and some miscellaneous reports can be purchased from the SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 20402. Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted, and cash is sent at the sender's risk. Book publications of the series listed above may also be purchased on an over-the-counter basis from the Geological Survey Public Inquiries Offices listed on page A245.

"Geophysical Abstracts" and "Abstracts of North American Geology," and some miscellaneous reports can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted, and cash is sent at the sender's risk. Book publications of the series listed above may also be purchased on an over-the-counter basis from the Geological Survey Public Inquiries Offices listed on page A245.

A235
American Geology" are available on subscription at rates described in the Survey's monthly announcement, "New Publications of the Geological Survey." A subscription to this monthly announcement—a catalog of publications (1879–1961) with annual supplements—circulars, and some miscellaneous reports may be obtained free on application to the U.S. Geological Survey, WASHINGTON, D.C. 20242.

Ordering maps and charts
Maps and charts, including folios and hydrologic atlases, are sold by the U.S. Geological Survey. Address mail orders to DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, 1200 SOUTH EADS STREET, ARLINGTON, VA. 22202, for maps of areas east of the Mississippi River, including Puerto Rico and the Virgin Islands, and to DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLO. 80225, for maps of areas west of the Mississippi, including Alaska, Hawaii, Louisiana, Minnesota, Guam, and American Samoa. An order for both eastern and western maps should be sent to the closer of the two distribution sections listed above. Residents of Alaska may order Alaska maps from DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, 310 FIRST AVENUE, FAIRBANKS, ALASKA 99701.

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. Prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. Prices include the cost of surface transportation. On an order amounting to $20 or more at the list price, 20 percent discount is allowed, on an order of $100 or more, 40 percent discount is allowed.

Maps and charts may be purchased over the counter at the following U.S. Geological Survey offices: 1200 South Eads Street, Arlington, Va.; 1028 General Services Administration Building, 19th and F. Streets, N.W., Washington, D.C.; 1100 North Highland Street, Arlington, Va.; 900 Pine Street, Rolla, Mo.; Building 41, Federal Center, Denver, Colo.; 345 Middlefield Road, Menlo Park, Calif.; 445 Federal Building, 700 West Ninth Street, Juneau, Alaska; 310 First Avenue, Fairbanks, Alaska; and Public Inquiries Offices listed on page A245.

Geological Survey maps are also sold by 690 authorized commercial dealers throughout the United States. Prices charged are generally higher than those charged by Survey offices.

Indexes to topographic-map coverage of the various States, Puerto Rico and the Virgin Islands, and Guam and American Samoa are released periodically and are free on application. The release of revised indexes is announced in the monthly list "New Publications of the Geological Survey." Each State index shows the areas mapped, with listings of special and United States maps, and gives lists of Geological Survey offices from which maps may be purchased and also of local agents who sell maps.

Advance material available from current topographic mapping is indicated on quarterly releases. This material, including such items as aerial photography, geodetic control data, and preliminary maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is given on the quarterly issues. Requests for indexes or inquiries concerning availability of this material should be directed to the MAP INFORMATION OFFICE, U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

State surface-water and quality-of-water records
Pending resumption of publication of surface-water records and quality-of-water records in the water-supply paper series, streamflow and quality-of-water records are being released in separate annual reports that are entitled "Water Resources Data for [State]" and consist of two parts: "Part 1, Surface Water Records," and "Part 2, Water Quality Records," on the basis of State boundaries. Distribution of these basic-data reports, which are free on request, is limited and is primarily for local needs. Those interested should write to the State or States for which records are needed.

State water-resources investigations folders
A series of 8- by 10¼-inch folders entitled "Water Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, the Virgin Islands, Guam, American Samoa, and Okinawa. As the programs change, the folders are revised. The folders are available free on request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

State lists of publications on hydrology and geology
A series of 6- by 9-inch booklets entitled "Geologic and Water-Supply Reports and Maps, [State]" provide a ready reference to these publications on a State basis. The booklets, which also list libraries in the subject State where Survey reports and maps may be consulted, are available free on request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Open-file reports
Open-file reports include unpublished manuscript reports, maps, and other material made available for
public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation by the public are given in press releases or other forms of public announcement. In general, open-file reports are placed in one or more of the three Geological Survey libraries: ROOM 1033, GENERAL SERVICES BLDG., WASHINGTON, D.C.; BLDG. 25, FEDERAL CENTER, DENVER, COLO.; and 345 MIDDLEFIELD ROAD, MENLO PARK, CALIF. Other depositories may include one or more of the Geological Survey offices listed on pages A245 to A249, or interested State agencies. Many open-file reports are replaced later by formally printed publications.
COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1969

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1969, signed by the Director of the Geological Survey and a responsible official of the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency.

FEDERAL COOPERATORS

Agency for International Development
Appalachian Regional Commission
Atomic Energy Commission:
Division of Raw Materials
Division of Reactor Development and Technology
Los Alamos Scientific Laboratory
National Reactor Testing Station
Nevada Operations Office
San Francisco Operations Office
Savannah River Operations Office
Department of Agriculture:
Agricultural Research Service
Forest Service
Soil Conservation Service
Department of the Air Force:
Air Force Academy
Alaskan Air Command
Andersen Air Force Base
Cambridge Research Center
Edwards Air Force Base
George Air Force Base
Kirtland Air Force Base
McChord Air Force Base
Special Weapons Center
Technical Applications Center
Vandenberg Air Force Base
Department of the Army:
Army Research Office
Corps of Engineers
Fort Wingate Army Depot
Pueblo Army Depot
Sierra Army Depot
Terrestrial Sciences Center
White Sands Missile Range
Department of Defense, Defense Intelligence Agency
Department of Health, Education, and Welfare, Public Health Service
Department of Housing and Urban Development
Department of the Interior—Continued
Office of Saline Water
Office of Water Resources Research
Department of Justice
Department of the Navy:
Marine Corps
Naval Weapons Center
Office of Naval Petroleum and Oil Shale Reserves
Office of Naval Research
Department of State:
International Boundary and Water Commission
International Joint Commission
Department of Transportation:
Coast Guard
Federal Highway Administration
Environmental Science Services Administration
Environmental Science Services Administration, Weather Bureau
Four Corners Regional Commission
National Aeronautics and Space Administration
National Science Foundation
Office of Emergency Preparedness
Tennessee Valley Authority
Veterans Administration

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
Alabama Department of Conservation
Alabama Highway Department
City of Mobile
City of Montgomery, Water Works and Sanitary Sewer Board
Geological Survey of Alabama

Alaska:
City of Anchorage
City of Kenai
Greater Anchorage Area Borough
Greater Juneau Borough
Kenai Peninsula Borough
Kodiak Island Borough
State Department of Fish and Game
State Department of Health and Welfare
State Department of Highways

Arizona:
Apache County Superior Court
Arizona Highway Department
Arizona Interstate Stream Commission
Arizona State Land Department
Buckeye Irrigation Company

Department of the Interior—Continued
Office of Saline Water
Office of Water Resources Research
Department of Justice
Department of the Navy:
Marine Corps
Naval Weapons Center
Office of Naval Petroleum and Oil Shale Reserves
Office of Naval Research
Department of State:
International Boundary and Water Commission
International Joint Commission
Department of Transportation:
Coast Guard
Federal Highway Administration
Environmental Science Services Administration
Environmental Science Services Administration, Weather Bureau
Four Corners Regional Commission
National Aeronautics and Space Administration
National Science Foundation
Office of Emergency Preparedness
Tennessee Valley Authority
Veterans Administration
Arizona—Continued
City of Flagstaff
City of Safford
City of Tucson
City of Williams
Flood Control District of Maricopa County
Gila Valley Irrigation District
Maricopa County Municipal Water Conservation District
No. 1 Metropolitan Water District of Southern California
Navajo Tribal Council
Pima County Board of Supervisors
Salt River Valley Water Users' Association
San Carlos Irrigation and Drainage District
Show Low Irrigation Company
State Game and Fish Department
University of Arizona

Arkansas:
Agricultural Experiment Station, University of Arkansas
Arkansas Geological Commission
Arkansas State Highway Commission

California:
Alameda County Flood Control and Water Conservation District
Alameda County Water District
Antelope Valley-East Kern Water Agency
Big Bear Lake Pest Abatement District
Board of Supervisors, County of San Benito
Bolinas Harbor District
California Department of Conservation, Division of Soil Conservation
California Department of Water Resources
California Division of Highways, Department of Public Works
City and County of San Francisco, Public Utilities Commission
City of San Diego
City of Santa Barbara
Coachella Valley Water District
Contra Costa County Flood Control and Water Conservation District
County of San Mateo
County of Ventura, Flood Control District
Department of Conservation, Division of Mines and Geology
Department of Fish and Game
Department of Water Resources
Desert Water Agency
East Bay Municipal Utility District
Georgetown Divide Public Utility District
Imperial Irrigation District
Kings River Conservation District
Lake County Flood Control and Water Conservation District
Los Angeles County, Department of County Engineers
Mojave Water Agency
Montecito County Water District
Monterey County Flood Control District
Newhall County Water District
Orange County Flood Control District
Orange County Water District
Paradise Irrigation District
Ridgecrest County Flood Control and Water Conservation District
California—Continued
Riverside County Flood Control and Water Conservation District
San Benito County Water Conservation and Flood Control District
San Bernardino County Flood Control District
San Bernardino Valley Water Conservation District
San Bernardino Valley Municipal Water District
San Diego County Flood Control and Water Conservation District
San Francisco Water Department
San Luis Obispo County Flood Control and Water Conservation District
Santa Barbara County Water Agency
Santa Clara County Flood Control and Water District
Santa Cruz County Flood Control and Water Conservation District
Santa Maria Valley Water Conservation District
State of California, Reclamation Board
Tehachapi-Cummings County Water District
Terra Bella Irrigation District
Turlock Irrigation District
United Water Conservation District
University of California
Ventura River Municipal Water District
Water Resources Control Board
Westlands Water District
Woodbridge Irrigation District

Colorado:
Arkansas River Compact Administration
City of Aurora, Department of Public Utilities
City of Colorado Springs, Department of Public Utilities
City and County of Denver, Board of Water Commissioners
Colorado Geological Survey
Colorado River Water Conservation District
Colorado Water Conservation Board
Denver Regional Council of Governments
Lower South Platte Conservancy District
Office of State Engineer
Plains Ground Water Management District
Southeastern Colorado Water Conservancy District
State Department of Highways, Division of Highways

Connecticut:
City of Hartford, Department of Public Works
City of New Britain, Board of Water Commissioners
City of Torrington
Connecticut Geological and Natural History Survey
Connecticut State Highway Department
Connecticut Water Resources Commission
Greater Hartford Flood Commission

District of Columbia:
Department of Sanitary Engineering

Delaware:
Delaware Geological Survey, University of Delaware
Delaware State Highway Department

Florida:
Broward County
Central and Southern Florida Flood Control District
City of Boca Raton
City of Dania
City of Fort Lauderdale
City of Hallandale
City of Jacksonville
City of Miami Beach
Florida—Continued
- City of Miami Department of Water and Sewers
- City of Naples
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Collier County
- Dade County
- Dade County Port Authority
- Florida Board of Conservation
- Florida Board of Conservation, Division of Geology
- Florida Board of Parks and Historic Memorials
- Florida State Road Department
- Hillsborough County
- Orange County
- Polk County
- Trustees of the Internal Improvement Fund

Georgia:
- Division of Conservation, Department of Mines, Mining, and Geology
- State Highway Department
- Water Quality Control Board

Hawaii:
- City and County of Honolulu
- City and County of Honolulu, Board of Water Supply
- Department of Land and Natural Resources, Division of Water and Land Development

Idaho:
- Idaho Department of Highways
- Idaho Department of Reclamation

Illinois:
- City of Springfield
- Cook County, Forest Preserve District
- Fountain Head Drainage District
- Northeastern Illinois Planning Commission
- Sanitary District of Bloom Township
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education:
  - Geological Survey Division
  - Water Survey Division
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois, Civil Engineering Department

Indiana:
- Indiana Department of Natural Resources
- Indiana Department of Natural Resources, Division of Water
- Indiana State Board of Health
- Indiana State Highway Commission

Iowa:
- City of Cedar Rapids
- City of Fort Dodge
- City of Iowa City
- Iowa Geological Survey
- Iowa Institute of Hydraulic Research
- Iowa State Conservation Commission
- Iowa State Highway Commission, Iowa Highway Research Board
- Iowa State University
- Iowa State University, Iowa Agricultural Experiment Station
- Linn County

Kansas:
- City of Wichita
- Kansas State Department of Agriculture
- Kansas State Department of Health
- Kansas State Geological Survey
- Kansas State Water Resources Board
- State Highway Commission of Kansas

Kentucky:
- City-County Planning Commission of Lexington and Fayette County
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky Research Foundation

Louisiana:
- Louisiana Department of Conservation
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Compact Administration

Maine:
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- City of Baltimore, Bureau of Water Supply
- Maryland Department of Health
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Maryland State Roads Commission
- Washington Suburban Sanitary Commission

Massachusetts:
- Massachusetts Metropolitan District Commission Water Division
- Massachusetts Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources
- Massachusetts Department of Public Works:
  - Division of Highways
  - Division of Highways, Bureau of Transportation, Planning, and Development
  - Division of Waterways

Michigan:
- Michigan Department of Natural Resources:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Minnesota Department of Administration
- Minnesota Department of Conservation, Division of Waters
- Minnesota Department of Highways
- Minnesota Geological Survey
- Minnesota Iron Range Resources and Rehabilitation Commission

Mississippi:
- City of Jackson
- Harrison County Board of Supervisors
- Harrison County Development Commission
- Jackson County Board of Supervisors
- Jackson County Port Authority
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological, Economic, and Topographical Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pearl River Basin Development District
- Pearl River Valley Water Supply District
- Washington County Board of Supervisors
COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1969

Missouri:
Curators of the University of Missouri
Metropolitan St. Louis Sewer District
Missouri Conservation Commission, Fisheries Division
Missouri Division of Geological Survey and Water Resources
Missouri State Highway Commission
Missouri Water Pollution Board
Montana:
Endowment and Research Foundation—Montana State University
Montana Bureau of Mines and Geology
Montana State Fish and Game Commission
Montana State Highway Commission
Montana Water Resources Board
Wyoming State Engineer
New York—Continued
Hudson River–Black River Regulating District
Nassau County Department of Public Works
New York City Department of Water Supply, Gas and Electricity and New York City Board of Water Supply
New York State Department of Conservation, Division of Water Resources
New York State Department of Health, Pollution Control Board
New York State Department of Transportation
Onondaga County Department of Public Works
Onondaga County Water Authority
Oswegatchie River–Cranberry Reservoir Commission
Suffolk County Board of Supervisors
Suffolk County Water Authority
Village of Nyack, Water Department
North Carolina:
City of Asheville
City of Burlington
City of Charlotte
City of Durham
City of Greensboro
City of Lenoir
City of Morganton
City of Winston-Salem
North Carolina Department of Conservation and Development, Division of Mineral Resources
North Carolina Department of Water and Air Resources
North Carolina State Highway Commission
North Carolina State University
Town of Waynesville
Wake County Board of Commissioners
North Dakota:
North Dakota Geological Survey
Oliver County
State Highway Department
State Water Commission
Ohio:
City of Columbus, Department of Public Works
Miami Conservancy District
Ohio Department of Health
Ohio Department of Highways
Ohio Department of Natural Resources:
Division of Geological Survey
Division of Water
Ohio River Valley Water Sanitation Commission
Oklahoma:
City of Oklahoma City
Oklahoma Department of Highways
Oklahoma Geological Survey
Oklahoma Soil Conservation Board
Oklahoma Water Resources Board
State Department of Health
Oregon:
Burnt River Irrigation District
City of Astoria
City of Coos Bay–North Bend, Water Board
City of McMinnville, Water and Light Department
City of Portland, Bureau of Water Works
City of The Dalles
City of Toledo
County of Coos, Board of Commissioners
County of Douglas, County Court
County of Lane, Board of Commissioners

Nebraska:
Hamilton County Ground Water Conservation District
Nebraska Department of Game and Parks Commission
Nebraska Department of Health
Nebraska Department of Water Resources
Nebraska Soil and Water Conservation Commission
Salt Valley Watershed District
State Department of Roads
University of Nebraska, Conservation and Survey Division
York County Ground Water Conservation District
New Hampshire:
New Hampshire Department of Resources and Economic Development
New Hampshire Water Resources Board
New Jersey:
County of Bergen
Delaware River Basin Commission
New Jersey Department of Conservation and Economic Development:
Division of Fish and Game
Division of Water Policy and Supply
New Jersey Department of Health, Division of Clean Air and Water
New Jersey Department of Transportation
North Jersey District Water Supply Commission
Passaic Valley Water Commission
Water Resources Research Institute at Rutgers, The State University
New Mexico:
Albuquerque Metropolitan Arroyo Flood Control Authority
City of Gallup
Costilla Creek Compact Commission
Interstate Stream Commission
New Mexico School of Mines
New Mexico State Engineer
New Mexico State Highway Commission
Pecos River Commission
Rio Grande Compact Commission
New York:
Brighton Sewer Commission District No. 2
City of Albany
City of Auburn
County of Westchester
Dutchess County Board of Supervisors
New York—Continued
Hudson River–Black River Regulating District
Nassau County Department of Public Works
New York City Department of Water Supply, Gas and Electricity and New York City Board of Water Supply
New York State Department of Conservation, Division of Water Resources
New York State Department of Health, Pollution Control Board
New York State Department of Transportation
Onondaga County Department of Public Works
Onondaga County Water Authority
Oswegatchie River–Cranberry Reservoir Commission
Suffolk County Board of Supervisors
Suffolk County Water Authority
Village of Nyack, Water Department
North Carolina:
City of Asheville
City of Burlington
City of Charlotte
City of Durham
City of Greensboro
City of Lenoir
City of Morganton
City of Winston-Salem
North Carolina Department of Conservation and Development, Division of Mineral Resources
North Carolina Department of Water and Air Resources
North Carolina State Highway Commission
North Carolina State University
Town of Waynesville
Wake County Board of Commissioners
North Dakota:
North Dakota Geological Survey
Oliver County
State Highway Department
State Water Commission
Ohio:
City of Columbus, Department of Public Works
Miami Conservancy District
Ohio Department of Health
Ohio Department of Highways
Ohio Department of Natural Resources:
Division of Geological Survey
Division of Water
Ohio River Valley Water Sanitation Commission
Oklahoma:
City of Oklahoma City
Oklahoma Department of Highways
Oklahoma Geological Survey
Oklahoma Soil Conservation Board
Oklahoma Water Resources Board
State Department of Health
Oregon:
Burnt River Irrigation District
City of Astoria
City of Coos Bay–North Bend, Water Board
City of McMinnville, Water and Light Department
City of Portland, Bureau of Water Works
City of The Dalles
City of Toledo
County of Coos, Board of Commissioners
County of Douglas, County Court
County of Lane, Board of Commissioners
Oregon—Continued
Department of Fisheries and Wildlife—Oregon State University
Eugene Water and Electric Board
Jackson County
Oregon State Board of Higher Education
Oregon State Game Commission
Oregon State Highway Commission
Oregon State Water Resources Board
State Engineer of Oregon
Water Resources Department, Office of the State Engineer

Pennsylvania:
Bucknell University
Chester County Water Resources Authority
City of Bethlehem
City of Easton
City of Harrisburg
City of Philadelphia
Commonwealth of Pennsylvania, Department of Highways
Commonwealth of Pennsylvania Department of Mines and Mineral Industries
Delaware River Master
Lehigh County Soil and Water Conservation District
Pennsylvania Department of Agriculture, State Soil and Water Conservation Commission
Pennsylvania Department of Forests and Waters, Water and Power Resources Board
Pennsylvania State Planning Board, Topographic and Geologic Survey
Pennsylvania State University

Rhode Island:
City of Providence, Department of Public Works
Rhode Island State Department of Natural Resources, Division of Harbors and Rivers
Rhode Island State Department of Public Works, Division of Roads and Bridges
State Water Resources Coordinating Board

South Carolina:
City of Spartanburg
Commissioners of Public Works, Spartanburg Water Works
Spartanburg County Planning and Development Commission
South Carolina State Development Board
South Carolina State Highway Department
South Carolina State Pollution Control Authority
South Carolina State Public Service Authority
South Carolina Water Resources Committee

South Dakota:
Black Hills Conservancy Subdistrict
City of Sioux Falls
East-Dakota Conservancy Subdistrict
South Dakota Department of Highways
South Dakota State Geological Survey
South Dakota State Water Resources Commission

Tennessee—Continued
Tennessee Department of Conservation:
Division of Water Resources
Division of Geology
Tennessee Department of Highways
Tennessee Department of Public Health, Stream Pollution Control
Tennessee Game and Fish Commission

Texas:
City of Dallas
City of Fort Worth
City of Houston
County of Dallas
Orange County Commissioners Court and Sabine River Authority of Texas
Pecos River Commission
Sabine River Compact Commission
Texas A and M University
Texas Highway Department
Texas Water Development Board

Utah:
Bear River Commission
Salt Lake County
Utah Department of Natural Resources:
Division of Water Resources
Division of Water Rights
Utah Geological and Mineralogical Survey
Utah State Road Commission

Vermont:
Vermont Department of Highways
Vermont Geological Survey
Vermont Water Resources Board

Virginia:
City of Alexandria
City of Newport News
City of Norfolk:
Department of Public Works
Division of Water Supply
City of Roanoke
City of Staunton
County of Chesterfield
County of Fairfax
Virginia Department of Conservation and Economic Development:
Division of Mineral Resources
Division of Water Resources
Virginia Department of Highways

Washington:
City of Port Angeles
City of Seattle, Department of Lighting
City of Tacoma:
Department of Public Utilities
Department of Public Works
Cowlitz County and Clark County Public Utility Districts
Municipality of Metropolitan Seattle
Port of Seattle
Washington State Department of Fisheries
Washington State Department of Game
Washington State Department of Highways
Washington State Department of Natural Resources, Division of Mines and Geology
Washington State Department of Water Resources
Washington State Pollution Control Commission
Western Washington State College
West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Natural Resources
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey
- West Virginia State Road Commission

Wisconsin:
- Regents of the University of Wisconsin, Geological and Natural History Survey
- Southeastern Wisconsin Regional Planning Commission
- Wisconsin Department of Natural Resources, Division of Conservation
- Wisconsin Department of Transportation, Division of Highways

Wyoming:
- City of Casper, Board of Public Utilities
- City of Cheyenne, Board of Public Utilities
- Office of the State Engineer
- Wyoming Game and Fish Commission
- Wyoming Geological Survey

Wyoming—Continued
- Wyoming Highway Department
- Wyoming Natural Resource Board
- Wyoming State Department of Agriculture
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Government of American Samoa
Governor of Guam
Government of the Virgin Islands
Kingdom of Saudi Arabia
Permittees and licensees of the Federal Power Commission
Puerto Rico:
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Industrial Research, Economic Development Administration
- Puerto Rico Department of Public Works
- Puerto Rico Mining Commission
- Trust Territory of the Pacific Islands
U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets N.W., Washington, D.C. 20242; 202 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; 303 233-3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 325-6761

PUBLIC INQUIRIES OFFICES

<table>
<thead>
<tr>
<th>Location</th>
<th>Official in charge and telephone number</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska, Anchorage 99501</td>
<td>Margaret I. Erwin (277-0577)</td>
<td>108 Skyline Bldg., 508 2d Ave.</td>
</tr>
<tr>
<td>California, Los Angeles 90012</td>
<td>Lucy E. Birdsall (213 688-2850)</td>
<td>7638 Federal Bldg., 300 N. Los Angeles St.</td>
</tr>
<tr>
<td>San Francisco 94111</td>
<td>Jean V. Molleskog (415 556-5627)</td>
<td>504 Custom House, 555 Battery St.</td>
</tr>
<tr>
<td>Colorado, Denver 80202</td>
<td>Lorene C. Young (303 297-4169)</td>
<td>1012 Federal Bldg., 1961 Stout St.</td>
</tr>
<tr>
<td>Texas, Dallas 75202</td>
<td>Mary E. Reid (214 749-3230)</td>
<td>602 Thomas Bldg., 1314 Wood St.</td>
</tr>
<tr>
<td>Utah, Salt Lake City 84111</td>
<td>Maurine Clifford (801 524-3652)</td>
<td>8102 Federal Bldg., 125 S. State St.</td>
</tr>
<tr>
<td>Washington, Spokane 99201</td>
<td>Eva M. Raymond (509 838-4611, ext. 111)</td>
<td>678 U.S. Court House, West 920 Riverside Ave.</td>
</tr>
</tbody>
</table>

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of July 1, 1969. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

<table>
<thead>
<tr>
<th>Location</th>
<th>Official in charge and telephone number</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona, Flagstaff 86001</td>
<td>Frederick B. Sower (602 774-1311, 1312)</td>
<td>601 E. Cedar Ave.</td>
</tr>
<tr>
<td>California, Menlo Park 94025</td>
<td>James L. Mueller (415 325-2660, 2661)</td>
<td>345 Middlefield Rd.</td>
</tr>
<tr>
<td>Missouri, Rolla 65401</td>
<td>Keith M. Beardsley (314 364-6985)</td>
<td>P.O. Box 41.</td>
</tr>
</tbody>
</table>

CONSERVATION DIVISION

The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification

<table>
<thead>
<tr>
<th>Location</th>
<th>Official in charge and telephone number</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska, Anchorage 99501</td>
<td>Leo H. Saarela (m) (907 277-0578), Alexander A. Wanek (c) (907 277-0570), W. J. Linton (o) (907 277-0579)</td>
<td>P.O. Box 259; 207-208 Skyline Bldg., 218 E St.</td>
</tr>
<tr>
<td>California, Los Angeles 90012</td>
<td>William C. Gere (c) (213 688-2846), D. W. Solanas (o) (213 688-2846)</td>
<td>7744 Federal Bldg., 300 N. Los Angeles St.</td>
</tr>
<tr>
<td>Bakersfield 93301</td>
<td>Harry Lee Wolf (o), vacant (c) (805 323-7676)</td>
<td>309 Federal Bldg., 800 Truxtun Ave.</td>
</tr>
<tr>
<td>Menlo Park 94025</td>
<td>Donal F. Ziehl (w) (415 325-6761, ext. 563, 564), Larry Godwin (c) (415 325-2563)</td>
<td>345 Middlefield Road.</td>
</tr>
<tr>
<td>Denver 80225</td>
<td>George H. Horn (c) (303 233-8168)</td>
<td>Bldg. 25, Federal Center.</td>
</tr>
<tr>
<td>Durango 81302</td>
<td>Jerry W. Long (o) (303 247-5144)</td>
<td>P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.</td>
</tr>
<tr>
<td>Louisiana, Metairie 70002</td>
<td>Robert F. Evans (o), Gayle A. Oglesby (c) (504 527-2424)</td>
<td>P.O. Box 546; 336 Imperial Office Bldg., 3301 N. Causeway Blvd.</td>
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A245
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<th>Location</th>
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<tr>
<td><strong>Montana, Billings 59103</strong></td>
<td>Albert F. Czarnecki (m) (406 245-8711, ext. 6383), Elmer M. Schell (o) (406 245-6711, ext. 6367)</td>
<td>P.O. Box 2550; 217 Post Office B’deg.</td>
</tr>
<tr>
<td><strong>Great Falls 59401</strong></td>
<td>Andrew F. Bateman (o) (406 761-3314), John D. Rosen (o) (406 761-3336)</td>
<td>P.O. Boxes 2265 and 1215; 510 1st Ave. N.</td>
</tr>
<tr>
<td><strong>New Mexico, Artesia 88210</strong></td>
<td>James A. Knauf (o) (505 746-4841), Robert S. Fulton (m), James S. Hinds (o) (505 885-6454)</td>
<td>Drawer U; 200 Carper Bldg., 105 S. 4th St.</td>
</tr>
<tr>
<td><strong>Carlsbad 88220</strong></td>
<td>Elmer M. Schell (c) (406 245-6711, ext. 6367), John D. Rosen (o) (406 761-3336)</td>
<td>P.O. Box 1716; Federal Bldg., 114 S. Halagueno St.</td>
</tr>
<tr>
<td><strong>Farmington 87401</strong></td>
<td>Philip T. McGrath (o), J. E. Fassett (o) (505 325-4572)</td>
<td>P.O. Box 959; 409 Petroleum Cub Plaza, 3535 E. 30th St.</td>
</tr>
<tr>
<td><strong>Hobbs 88240</strong></td>
<td>Arthur R. Brown (o) (505 393-3612)</td>
<td>Box 1157; 205 N. Linam St.</td>
</tr>
<tr>
<td><strong>Roswell 88201</strong></td>
<td>J. A. Anderson (o) (505 622-9857), Donald M. Van Sickle (o) (505 622-1332)</td>
<td>Drawer U; 200 Carper Bldg., 105 S. 4th St.</td>
</tr>
<tr>
<td><strong>Oklahoma, Holdenville 74848</strong></td>
<td>Gerhardt H. W. Schuster (o) (405 379-3840), Alex M. Dinamore (m) (918 423-5030)</td>
<td>P.O. Box 1152; 217 Post Office B’deg.</td>
</tr>
<tr>
<td><strong>McAlester 74501</strong></td>
<td>Claro V. Collins (m) (918 542-9481)</td>
<td>P.O. Box 959; 409 Petroleum Cub Plaza, 3535 E. 30th St.</td>
</tr>
<tr>
<td><strong>Miami 74354</strong></td>
<td>Charley W. Nease (o) (405 236-2278)</td>
<td>P.O. Box 959; 409 Petroleum Cub Plaza, 3535 E. 30th St.</td>
</tr>
<tr>
<td><strong>Oklahoma City 73102</strong></td>
<td>Edward L. Johnson (c) (918 584-7638), Orvis Frederick (o) (918 584-7632)</td>
<td>4562 New Federal Bldg., 333 W. 4th St.</td>
</tr>
<tr>
<td><strong>Tulsa 74103</strong></td>
<td>Loyd L. Young (w) (503 234-3996)</td>
<td>P.O. Box 3087, 319 Post Office B’deg.</td>
</tr>
<tr>
<td><strong>Utah, Salt Lake City 84111</strong></td>
<td>Ernest Blessing (m) (801 524-5646), Rodney A. Smith (o) (801 524-5650), Howard P. Albee (o) (801 524-5643)</td>
<td>P.O. Box 1152; 244 Federal Bldg.</td>
</tr>
<tr>
<td><strong>Washington, Tacoma 98401</strong></td>
<td>Gordon C. Giles (w) (206 383-5380)</td>
<td>P.O. Box 900; 305 Federal Bldg.</td>
</tr>
<tr>
<td><strong>Wyoming, Casper 82601</strong></td>
<td>Glenn E. Worden (o) (307 746-4554)</td>
<td>P.O. Box 219; 214 W. Main St.</td>
</tr>
<tr>
<td><strong>Newcastle 82701</strong></td>
<td>John A. Fraher (o) (307 407-6242), Arne A. Mattila (m) (307 407-3750)</td>
<td>P.O. Box 590; 202 Federal Bldg.</td>
</tr>
<tr>
<td><strong>Thermopolis 82443</strong></td>
<td>Charles P. Clifford (o) (307 864-3477)</td>
<td>P.O. Box 590; 202 Federal Bldg.</td>
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**GEOLOGIC DIVISION**

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<tr>
<th>Location</th>
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<tbody>
<tr>
<td><strong>Alaska, College 99735</strong></td>
<td>Robert M. Chapman (479-7243)</td>
<td>P.O. Box 580; Brooks Memorial Bldg. 601 E. Cedar Ave.</td>
</tr>
<tr>
<td><strong>Arizona, Flagstaff 86001</strong></td>
<td>Alfred H. Chidester (602 774-1455)</td>
<td>P.O. Box 271, 8604 La Jolla Drs.</td>
</tr>
<tr>
<td><strong>California, La Jolla 92037</strong></td>
<td>George W. Moore (714 453-2820, ext. 341)</td>
<td>Hawaiian Volcano Observatory. 710 W. High St.</td>
</tr>
<tr>
<td><strong>Hawaii, Hawaii National Park 96718</strong></td>
<td>Howard A. Powers (678-485)</td>
<td>U.S. Geological Survey Bldg., Dept. of Agriculture Research Center. 80 Broad St.</td>
</tr>
<tr>
<td><strong>Maryland, Beltsville 20705</strong></td>
<td>Lincoln R. Page (617 223-7202)</td>
<td>Orton Hall, Ohio State Univ., 155 S. Oval Drive.</td>
</tr>
<tr>
<td><strong>Massachusetts, Boston 02110</strong></td>
<td>John S. Schle (617 548-140, ext. 298)</td>
<td>P.O. Box 4862, Station A; Geology Bldg., Univ. of New Mexico. 223 Science Hall, Univ. of Wisconsin.</td>
</tr>
<tr>
<td><strong>New Mexico, Albuquerque 87106</strong></td>
<td>Charles B. Read (505 247-0311, ext. 483)</td>
<td>P.O. Box 372, 1201 U.S. Geological Survey, Bldg. 11 Post Office Bldg.</td>
</tr>
<tr>
<td><strong>Ohio, Columbus 43210</strong></td>
<td>James M. Schopf (614 294-1810)</td>
<td>P.O. Box 380. 11 Post Office Bldg. 801 Federal Center.</td>
</tr>
<tr>
<td><strong>Puerto Rico, Roosevelt 00929</strong></td>
<td>Reginald P. Briggs (Hato Rey 766-5340)</td>
<td>P.O. Box 308. 11 Post Office Bldg. 801 Federal Center.</td>
</tr>
<tr>
<td><strong>Tennessee, Knoxville 37902</strong></td>
<td>Robert A. Lawrence (615 524-4011, ext. 4261)</td>
<td>P.O. Box 900; 305 Federal Bldg. South 157 Howard St.</td>
</tr>
<tr>
<td><strong>Texas, Austin 78701</strong></td>
<td>D. Hove Eargle (512 476-6580)</td>
<td>P.O. Box 1918; 1901 N. Shoreline Drive E. 8426 Federal Bldg.</td>
</tr>
<tr>
<td><strong>Corpus Christi 78403</strong></td>
<td>Henry L. Berryhill, Jr. (512 883-5294)</td>
<td>P.O. Box 1918; 1901 N. Shoreline Drive E. 8426 Federal Bldg.</td>
</tr>
<tr>
<td><strong>Utah, Salt Lake City 84111</strong></td>
<td>Lowell S. Hilpert (801 524-5640)</td>
<td>223 Science Hall, Univ. of Wisconsin. 3007, Univ. Station; Geology Hall, Univ. of Wyoming.</td>
</tr>
<tr>
<td><strong>Washington, Spokane 99204</strong></td>
<td>Albert E. Welsenborn (509 339-3121)</td>
<td>223 Science Hall, Univ. of Wisconsin. 3007, Univ. Station; Geology Hall, Univ. of Wyoming.</td>
</tr>
<tr>
<td><strong>Wisconsin, Madison 53706</strong></td>
<td>Carl E. Dutton (608 262-1294, ext. 1854)</td>
<td>223 Science Hall, Univ. of Wisconsin. 3007, Univ. Station; Geology Hall, Univ. of Wyoming.</td>
</tr>
<tr>
<td><strong>Wyoming, Laramie 82071</strong></td>
<td>J. David Love (307 FRanklin 5-4495)</td>
<td>223 Science Hall, Univ. of Wisconsin. 3007, Univ. Station; Geology Hall, Univ. of Wyoming.</td>
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## TOPOGRAPHIC DIVISION

### SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

<table>
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<tr>
<th>Location</th>
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<tbody>
<tr>
<td>California, Menlo Park 94025</td>
<td>Roy F. Thurston (415 325-2411)</td>
<td>345 Middlefield Rd.</td>
</tr>
<tr>
<td>Missouri, Rolla 65401</td>
<td>Daniel Kennedy (314 364-3860)</td>
<td>P.O. Box 133; 9th and Elm Sta.</td>
</tr>
<tr>
<td>Virginia, Arlington 22201</td>
<td>James S. Crabtree (703 521-6555)</td>
<td>1109 N. Highland St.</td>
</tr>
</tbody>
</table>

## WATER RESOURCES DIVISION

### REGIONAL OFFICES

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<tr>
<th>Location</th>
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</thead>
<tbody>
<tr>
<td>Atlantic Coast Region:</td>
<td>George E. Ferguson, Regional Hydrologist (302 343-8841)</td>
<td>Rm. 317 George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.</td>
</tr>
<tr>
<td>Midcontinent Region:</td>
<td>Elwood R. Leeson, Regional Hydrologist (314 268-7224)</td>
<td>Suite 212, West Port 104 Building, 2272 Schuets Road.</td>
</tr>
<tr>
<td>Rocky Mountain Region:</td>
<td>Thad G. McLaughlin, Regional Hydrologist (303 233-6701)</td>
<td>Bldg. 25, Federal Center.</td>
</tr>
<tr>
<td>Pacific Coast Region:</td>
<td>Warren W. Hastings, Regional Hydrologist (415 325-6761, ext. 337, 339, 487)</td>
<td>345 Middlefield Rd.</td>
</tr>
</tbody>
</table>

## DISTRICT OFFICES

<table>
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<tr>
<th>Location</th>
<th>Official in charge and telephone number</th>
<th>Address</th>
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</thead>
<tbody>
<tr>
<td>Alabama, Tuscaloosa 35486</td>
<td>William L. Broadhurst (205 345-8226)</td>
<td>P.O. Box V; Oil and Gas Board Bldg., Univ. of Alabama.</td>
</tr>
<tr>
<td>Alaska, Anchorage 99501</td>
<td>Harry Huling (907 277-5526, 5527)</td>
<td>Skyline Bldg., 218 E St.</td>
</tr>
<tr>
<td>Arizona, Tucson 85717</td>
<td>Horace M. Babcock (902 792-6391, 6392)</td>
<td>6393.</td>
</tr>
<tr>
<td>California, Menlo Park 94025</td>
<td>R. Stanley Lord (415 325-6761, ext. 326, 327, 465, 466)</td>
<td>855 Oak Grove Ave.</td>
</tr>
<tr>
<td>Connecticut, Hartford 06101</td>
<td>John Horton (203 244-2528)</td>
<td>P.O. Box 715; Rm. 235, Post Office Bldg.</td>
</tr>
<tr>
<td>Delaware</td>
<td>Walter F. White, Jr. (301 828-7460)</td>
<td>See Maryland District Office.</td>
</tr>
<tr>
<td>District of Columbia</td>
<td>Walter F. White, Jr. (301 828-7460)</td>
<td>See Maryland District Office.</td>
</tr>
<tr>
<td>Florida, Tallahassee 32304</td>
<td>Clyde S. Conover (904 224-1202, 1203)</td>
<td>P.O. Box 2315.</td>
</tr>
<tr>
<td>Georgia, Atlanta 30309</td>
<td>John R. George (404 526-5663, 5664)</td>
<td>Rm. 301, 900 Peachtree St., N.E.</td>
</tr>
<tr>
<td>Hawaii, Honolulu 96814</td>
<td>Mearl M. Miller (546-5, 326, 465, 466)</td>
<td>Rm. 330, First Insurance Bldg., 1100 Ward Ave.</td>
</tr>
<tr>
<td>Idaho, Boise 83702</td>
<td>Willis L. Burnham (208 342-2711, ext. 539)</td>
<td>Rm. 365, Federal Bldg., 550 W. Post St.</td>
</tr>
<tr>
<td>Illinois, Champaign 61820</td>
<td>William D. Mitchell (217 359-3918)</td>
<td>P.O. Box 1026; 605 N. Neil St.</td>
</tr>
<tr>
<td>Indiana, Indianapolis 46204</td>
<td>Malcolm D. Hale (317 633-7396)</td>
<td>Rm. 516, 611 N. Park Ave.</td>
</tr>
<tr>
<td>Iowa, Iowa City 52240</td>
<td>Sulo W. Witala (319 338-0581, ext. 475)</td>
<td>Suite F, 1041 Arthur St.</td>
</tr>
<tr>
<td>Kansas, Lawrence 66044</td>
<td>Charles W. Lane (913 864-4321)</td>
<td>Rm. 768; USGS Bldg., West of 11th and Iowa Sts.</td>
</tr>
<tr>
<td>Kentucky, Louisville 40202</td>
<td>Floyd F. Schrader (502 582-5241, 5242, 5243)</td>
<td>Rm. 572, Federal Bldg., 600 Federal Place.</td>
</tr>
<tr>
<td>Louisiana, Baton Rouge 70806</td>
<td>Rex R. Meyer (504 348-4281)</td>
<td>Rm. 215, Prudential Bldg., 6554 Florida Blvd.</td>
</tr>
<tr>
<td>Maryland, Towson 21204</td>
<td>Walter F. White, Jr. (301 828-7460)</td>
<td>724 York Rd.</td>
</tr>
<tr>
<td>Massachusetts, Boston 02203</td>
<td>Charles E. Knox (617 223-2822)</td>
<td>Rm. 2300, John F. Kennedy Federal Bldg.</td>
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<tr>
<td>Michigan, Lansing 48933</td>
<td>Arlington D. Ash (517 372-1910, ext. 561)</td>
<td>Rm. 700, Capitol Savings and Loan Bldg.</td>
</tr>
<tr>
<td>Minnesota, St. Paul 55101</td>
<td>Charles R. Collier (612 725-7841, 7842)</td>
<td>Rm. 1002, New Post Office Bldg.</td>
</tr>
<tr>
<td>Mississippi, Jackson 39205</td>
<td>Lamar E. Carroon (601 948-7521, ext. 326)</td>
<td>P.O. Box 2052; Rm. 302, U.S. Post Office Bldg.</td>
</tr>
<tr>
<td>Missouri, Rolla 65401</td>
<td>Anthony Homyk, Jr. (314 364-1599)</td>
<td>P.O. Box 340; 103 W. 10th St.</td>
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### U.S. GEOLOGICAL SURVEY OFFICES

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<tr>
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<tr>
<td>Montana, Helena</td>
<td>George M. Pike (406 442-9040, ext. 3263)</td>
<td>P.O. Box 1696; Rm. 421, Federal Bldg.</td>
</tr>
<tr>
<td>Nebraska, Lincoln</td>
<td>Kenneth A. MacKiehan (402 475-3643)</td>
<td>Rm. 127, Nebraska Hall, 901 N. 17th St.</td>
</tr>
<tr>
<td>Nevada, Carson City</td>
<td>George F. Worts, Jr. (702 882-1386)</td>
<td>222 E. Washington St.</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Charles E. Knox (617 222-2822)</td>
<td>See Massachusetts District Office.</td>
</tr>
<tr>
<td>New Jersey, Trenton</td>
<td>John E. McCall (609 599-3511, ext. 212, 213)</td>
<td>P.O. Box 1238; Rm. 420, Federal Bldg.</td>
</tr>
<tr>
<td>New Mexico, Albuquerqrue</td>
<td>William E. Hale (505 247-2500)</td>
<td>P.O. Box 4369; Geology Bldg., Univ. of New Mexico.</td>
</tr>
<tr>
<td>New York, Albany</td>
<td>Robert J. Dingman (518 472-3107)</td>
<td>P.O. Box 948; Rm. 343, U.S. Post Office and Court House.</td>
</tr>
<tr>
<td>North Carolina, Raleigh</td>
<td>Ralph C. Heath (919 828-9031, ext. 126)</td>
<td>P.O. Box 2857; 4th Floor, Federal Bldg.</td>
</tr>
<tr>
<td>North Dakota, Bismarck</td>
<td>Harlan M. Erskine (701 255-4011, ext. 227, 228)</td>
<td>P.O. Box 778; Rm. 348, New Federal Bldg., 3d Street and Rosser Ave.</td>
</tr>
<tr>
<td>Ohio, Columbus</td>
<td>John J. Molloy (614 469-5553, 5554)</td>
<td>975 W. 3d Ave.</td>
</tr>
<tr>
<td>Oklahoma, Oklahoma City</td>
<td>John W. Odell (405 236-2511, ext. 257, 258)</td>
<td>Rm. 4301, Federal Bldg. and U.S. Court House, 200 N.W. 4th St.</td>
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<tr>
<td>Pennsylvania, Harrisburg</td>
<td>Norman H. Beamer (215 597-7366)</td>
<td>P.O. Box 1107, 4th Floor, 228 Walnut St.</td>
</tr>
<tr>
<td>Puerto Rico, San Juan</td>
<td>Dean B. Bogart (809 738-4660, 4469, 4788)</td>
<td>2d Floor, Bldg. 653 at Ft. Buchanan; Bldg. 652, U.S. Naval Station Annex.</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>Charles E. Knox (617 223-2822)</td>
<td>See Massachusetts District Office.</td>
</tr>
<tr>
<td>South Carolina, Columbia</td>
<td>John S. Stallings (803 253-8371, ext. 401)</td>
<td>2346 Two Notch Rd.</td>
</tr>
<tr>
<td>South Dakota, Huron</td>
<td>John E. Powell (605 352-8531, ext. 293, 294)</td>
<td>P.O. Box 1412; Rm. 231, Federal Bldg.</td>
</tr>
<tr>
<td>Tennessee, Nashville</td>
<td>Edward J. Kennedy (615 242-8321, ext. 5424)</td>
<td>144, Federal Bldg.</td>
</tr>
<tr>
<td>Texas, Austin</td>
<td>Trigg Twichell (512 475-5766, 5767, 5768)</td>
<td>Rm. 8002, Federal Bldg., 125 S. State St.</td>
</tr>
<tr>
<td>Utah, Salt Lake City</td>
<td>Theodore Arrow (801 524-5663, 5657, 5658)</td>
<td>Federal Bldg., 300 E. 8th Ave.</td>
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<tr>
<td>Virginia, Richmond</td>
<td>Charles E. Knox (617 223-2822)</td>
<td>See Massachusetts District Office.</td>
</tr>
<tr>
<td>Washington, Tacoma</td>
<td>Leslie B. Laird (206 383-2861, ext. 334)</td>
<td>200 W. Grace St.</td>
</tr>
<tr>
<td>West Virginia, Charleston</td>
<td>William C. Griffin (304 343-6181, ext. 310, 311)</td>
<td>Rm. 300, 1305 Tacoma Ave., South.</td>
</tr>
<tr>
<td>Wisconsin, Madison</td>
<td>Charles L. R. Holt, Jr. (608 262-2448)</td>
<td>Rm. 3303, New Federal Bldg. and U.S. Court House, 500 Quarrier St., East.</td>
</tr>
<tr>
<td>Wyoming, Cheyenne</td>
<td>Robert L. Cushman (307 778-2317, 2331, 2414, 2474)</td>
<td>Rm. 200, 1815 University Ave.</td>
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### OFFICES IN OTHER COUNTRIES

#### GEOLOGIC DIVISION

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<tr>
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<tr>
<td>Medellín</td>
<td></td>
<td>U.S. Geological Survey, c/o American Consulate, Medellín, Colombia.</td>
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### OFFICES IN OTHER COUNTRIES

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### WATER RESOURCES DIVISION

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<tr>
<th>Location</th>
<th>Official in charge</th>
<th>Address</th>
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INVESTIGATIONS IN PROGRESS IN THE CONSERVATION, GEOLOGIC, AND WATER RESOURCES DIVISIONS

Investigations in progress at the end of fiscal year 1969 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. A245, 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. The lowercase letter following the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; 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 is 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 a 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 (for example, 1:62,500; 1:24,000).

Abstracts. See Bibliographies and abstracts.

Analytical chemistry:
- Activation analysis (J. Rowe, W)
- Analytical methods—water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (I. May, W; C. Huffman, Jr., D; C. O. Ingamells, M)
- Chemical equilibrium and kinetic studies—surface and solution chemistry of aluminum hydroxides (R. W. Smith, w, M)
- Instrumentation (J. F. Abell, W)
- Natural organic macromolecules in water (R. L. Wershow, w, D)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances—pesticides—in water (D. F. Goerlitz, w, M)
- Pesticides, determination in water (G. Stratton, w, Columbus, Ohio)
- Radioactivation and radiocarbon chemistry (H. T. Millard, D)
- Radiometric methods of analysis (L. L. Thatcher, w, D)
- Recovery, separation, and identification of phenolic compounds from polluted water (S. D. Faust, w, Trenton, N.J.)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapito, W)
- Sample control (H. Bastron, M)
- Services (J. L. Ramisch, W; L. B. Riley, D)
- Trace analysis methods, research (F. N. Ward, D)
- Trace analysis service (K. W. Leong, M)
- Ultratrace analysis (H. T. Millard, D)
- Water analysis—methods manual (E. Brown, w, D)

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Artificial Recharge:
- Colorado, Kit Carson County (W. E. Hofstra, w, Denver)
- Florida:
  - Floridan aquifer, Orange County (W. F. Lichtier, w, Winter Park)
  - Floridan aquifer, west-central area (J. S. Rosenshein, w, Tampa)
- Injection of wastes in deep wells (D. A. Goosby, w, Ocala)
- New York, treated sewage through an injection well, East Park, Long Island (J. Vecchioli, w, Mineola)
- Texas, artificial recharge study—High Plains of Texas and New Mexico (R. F. Brown, w, Lubbock)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabbee, W)

Asphalt, California (A. E. Roberts, D)

Base metals:
- Colorado, Wet Mountains (Q. D. Singewald, Beltsville, Md.)
- Missouri, iron (P. W. Guild, W)

See also base-metal names.

Bibliographies and abstracts:
- Arid-land hydrology, bibliography (S. E. Rantz, w, M)
- Geophysical abstracts (J. W. Clarke, W)
- Hydrology of the United States and Canada, bibliography (N. M. Baker, w, W)
- Lunar bibliography (J. H. Freeberg, M)
- North American geology, bibliography (J. W. Clarke, W)
- Remote-sensing bibliography for earth resources, indexed, with notation of content (R. K. Llaverias, w, W)
- Sedimentation in coastal bodies of water, annotated, indexed (D. D. Carstea, w, W)
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Specific yield of ground water, California, annotated bibliography (A. J. Johnson, w, D)
Vanadium, geology and resources, bibliography (J. P. Ohl, D)
Water-resources selected abstracts, bibliography, input to Water Resources Scientific Information Center (J. W. Lang, w, W)

Borates:
Borate marshes, California, Nevada, and Oregon (W. C. Smith, M)

California:
Furnace Creek area (J. F. McAllister, M)
Searles Lake area (G. I. Smith, M)

Chromite, See Ferro-alloy metals.

Clays:
Clay chemistry (D. Carroll, M)
Appalachia, northern part (J. W. Hosterman, Beltsville, Md.)
Florida and Georgia, Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, Beltsville, Md.)

Coal:
Resourses of the United States (P. Averitt, D)

Alaska:
Bering River coal field (A. A. Wanek, c, Anchorage)
Kukpawrork River coal field (A. A. Wanek, c, Anchorage)
Nenana (C. Wahrhaftig, M)

Arizona:
Cummings Mesa quadrangle (F. Peterson, c, D)
Gunsight Butte SE and SW quadrangles (F. Peterson, c, D)
Navajo Reservation, fuels potential (R. B. O'Sullivan, D)

California:
Hernandez Valley quadrangle (E. E. Richardson, c, Bakersfield)
Priest Valley SE quadrangle (E. E. Richardson, c, Bakersfield)

Colorado:
Buckhorn Lake quadrangle (R. G. Dickinson, c, D)
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Kremmling quadrangle (G. A. Izett, c, D)
Mellen Hill quadrangle (H. L. Collins, c, D)
Peoria quadrangle (P. E. Soister, c, D)
Rangely 7K-minute quadrangle (H. L. Collins, c, D)
Rangely NE quadrangle (H. L. Collins, c, D)
Savery quadrangle (C. S. V. Barclay, c, D)
Strasburg NW and SW quadrangles (P. E. Soister, c, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins quadrangle (P. E. Soister, c, D)
Watkins SE quadrangle (P. E. Soister, c, D)

Montana:
Black Butte 30-minute quadrangle (A. F. Bateman, c, Great Falls)
Black John Coulee quadrangle (G. D. Mowat, c, Billings)
Hardy quadrangle (K. S. Soward, c, Great Falls)
Jordan 2 NE quadrangle (G. D. Mowat, c, Billings)
Jordan 2 SE quadrangle (G. D. Mowat, c, Billings)
Moorhead coal field (N. W. Bass, c, D)
Rocky Reef quadrangle (K. S. Soward, c, Great Falls)

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New Mexico:
Fruitland Formation (J. E. Fassett, c, Farmington)
Gallup West (J. E. Fassett, c, Farmington)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)

North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
New Salem quadrangle (H. L. Smith, c, D)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)

Pennsylvania:
Anthracite region, flood control (M. J. Bergin, W)
Claysville-Avella area (S. P. Schweinfurth, W)
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Southern anthracite field (G. H. Wood, Jr., W)
Waynesburg—Oak Forest area (J. B. Roen, Beltsville, Md.)
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Utah:
Canaan Creek quadrangle (H. D. Zeller, c, D)
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Gilbert Peak 1 NE quadrangle (E. M. Schell, c, Billings, Mont.)
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Wide Hollow Reservoir quadrangle (E. V. Stephens, c, D)

Virginia, Pocahontas coal beds (K. J. Englund, W)
West Virginia, low-sulfur resources (K. J. Englund, W)

Wyoming:
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
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Deer Creek quadrangle (D. A. Jobin, c, D)
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Jackson quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Jessen Butte area (E. M. Schell, c, Billings, Mont.)
Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
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Poison Spider quadrangle (W. H. Laraway, c, Casper)
Reid Canyon (W. H. Laraway, c, Casper)
Savery quadrangle (C. S. V. Barclay, c, D)
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Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Stewart Peak quadrangle (D. A. Jobin, c, D)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
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Deformation research (S. P. Kanizay, D)
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Engineering properties of rocks and soils (T. C. Nichols, Jr., D)
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Geologic environmental studies for land-use planning, California (C. M. Wentworth, Jr., M)
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Mudflow studies, Washington, Oregon, and Colorado (D. R. Crandell, D)
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Colorado:
Black Canyon of the Gunnison River (W. R. Hansen, D)
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Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)

Nevada:
Nevada Test Site, geophysics (R. D. Carroll, Flagstaff, Ariz.)
Nevada Test Site, site studies (P. P. Orkild, D; R. E. Davis, D)
Utah, coal-mine bumps (F. W. Osterwald, D)

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Contamination, water:

Distribution, source, and transport of organic pesticides in reservoir sediments (M. L. Yates, W, W)
Pesticide pollutants in water (R. L. Wershaw, W, D)
Alabama, sewage lagoon study (W. J. Powell, W, Tuscaloosa)
Massachusetts, ground-water contamination from highway salt (S. J. Pollock, W, Boston)
New Hampshire, ground-water contamination from highway salt (H. A. Whitcomb, W, Concord)

New York:
Abatement of pollution, southwestern Nassau County (N. M. Perlmutter, W, Mineola)
Cadmium-chromium and detergent contamination in ground water, Nassau County (N. M. Perlmutter, W, Mineola)
Detergents, contamination at three public-supply well fields, Suffolk County (N. M. Perlmutter, W, Mineola)
West Virginia, acid mine drainage, Grass River—Roaring Creek (J. T. Gallaher, W, Morgantown)

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Copper:

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Twin Buttes area (J. R. Cooper, D)

Michigan:
Greenland and Rockland quadrangles (J. W. Whitlow, Beltsville, Md.)
Michigan copper district (W. S. White, Beltsville, Md.)

Nevada, Copper Canyon deposit (J. L. Theodore, M)
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Crustal studies. See Earthquake studies; Geophysics, regional.

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Basement and volcanic rock studies along San Andreas fault (D. C. Ross, M)
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Geologic framework of San Andreas fault (T. W. Dibblee, Jr., M)

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Regional tectonic analysis (R. E. Wallace, M)

Colorado, Denver earthquake studies (D. B. Hoover, D)

Utah, Wasatch fault zone (M. E. Morisawa, D)

Ecology:

Biology of streams as related to hydrological, chemical, and physical factors (B. W. Lium, w, Salt Lake City, Utah)

Washington, influence of stream hydraulics on anadromous fish migration and propagation (M. R. Collings, w, Tacoma)

Engineering geologic studies. See Construction and terrain problems; Urban geology.

Evaporation:

Evaporation from lakes and reservoirs (J. S. Meyers, w, D)

Verification of mass-transfer and pan relations for large lakes and reservoirs, Salton Sea (A. M. Sturrock, Jr., w, Salton City, Calif.)

California, Vail Reservoir evaporation study (M. W. Bushy, w, Garden Grove)

Indiana, evaporation losses from lakes (J. E. Heisel, w, Indianapolis)

Nevada, Smith Creek Valley playa (F. E. Rush, J. R. Harrison, w, Carson City)

North Carolina:

Lake Michigan, evaporation analysis (J. F. Turner, w, Raleigh)

Roxboro Lake, evaporation and thermal-loading analysis (J. F. Turner, w, Raleigh)

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Evaporation suppression:

Mechanics of evaporation suppression and evaporation (G. E. Koberg, w, D)

Evapotranspiration:

Hydrologic effects of vegetative modification (R. M. Myrick, w, Tucson, Ariz.)

Phreatophytes and their effect on the hydrologic regimen (T. W. Robinson, w, M)

Use of water by salt cedar in evapotranspiration monitors, measured and computed by energy budget and mass transfer methods, Arizona (T. E. A. van Hylckama, w, Lubbock, Tex.)

Arizona:

Phreatophyte project, Gila River (R. C. Culler, w, Tucson)

Potential evapotranspiration loss of Agua Fria River (T. W. Anderson, w, Phoenix)

Study of effects of vegetation manipulation on surface runoff, Sycamore Creek (H. W. Hjalmarson, w, Phoenix)

California, root-zone conditions and plant-physiological processes as factors in phreatophyte evapotranspiration (O. M. Grosz, w, M)

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Selenography (D. W. G. Arthur, Flagstaff, Ariz.)

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Terrain analysis (L. C. Rowan, R. J. Pike, Flagstaff, Ariz.)

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Alabama, flood studies and bridge-site investigations (C. O. Ming, w, Tuscaloosa)
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Mississippi, bridge-site flood investigations (C. P. Humphreys jr., W, Jackson)
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New Mexico, peak flood-flow characteristics of small streams (A. G. Scott, w, Santa Fe)
North Dakota (O. A. Crosby, w, Bismarck)
Ohio (R. I. Mayo, w, Columbus)
Oregon, flood profiles, Rogue and Applegate Rivers (D. D. Harris, w, Portland)
South Carolina (B. H. Herstone, w, Columbia)
Tennessee (W. J. Randolph, w, Nashville)
Utah, bridge-site investigations (G. E. Pyper, w, Salt Lake City)
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Alabama, flood frequency syntheses for small streams (C. O. Ming, w, Tuscaloosa)
Colorado, Denver metropolitan area (D. D. Gonzalez, w, Denver)
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Flood frequency of small areas (J. L. Simmons, w, Baton Rouge)
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North Carolina, flood frequency and high-flow studies (H. G. Hinson, w, Raleigh)
Tennessee, magnitude and frequency of floods on small streams (I. J. Hickenlooper, w, Nashville)
Utah, magnitude and frequency (E. Butler, w, Salt Lake City)
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California, flood-inundation maps--southern California (M. Price, F. W. Glessner, F. W. Fenzel, J. A. Singer, w, Garden Grove)
Hawaii (R. Lee, w, Honolulu)
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Iowa, Squaw Creek, Linn County (H. H. Schwoeb, w, Iowa City)
Missouri, Metropolitan St. Louis Sewer District (D. W. Spencer, w, St. Louis)
Nebraska:
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<td>Buckhorn Lake quadrangle (R. G. Dickinson, c, D)</td>
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<td>Central City area (R. B. Taylor, D)</td>
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<td>Peoria quadrangle (P. E. Solster, c, D)</td>
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<td>Poncha Springs quadrangle (R. E. Van Alstine, W)</td>
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Southern Aroostook County (L. Pavlides, W)
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Western Neguaneau quadrangle (L. D. Clark, M)
Mississippi, Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)
Montana:
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Bearpaw Mountains petrology (B. C. Hearn, Jr.)
Black Butte 7½-minute quadrangle (L. M. McGrew, Laramie, Wyo.)
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Butte North quadrangle (H. W. Smedes, D)
Crazy Mountains Basin (B. A. Skipp, D)
Hardy quadrangle (K. S. Soward, c, Great Falls)
Henrys Lake area (L. J. Witkind, D)
Holter Lake quadrangle (G. D. Robinson, D)
Jordan 2 NE quadrangle (G. D. Mowat, c, Billings)
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Neihart 1 quadrangle (W. R. Keefer, D)
Ringling quadrangle (L. M. McGrew, Laramie, Wyo.)
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Wise River quadrangle (G. D. Fraser, c, D)
Wolf Creek area, petrology (R. G. Schmidt, W)
New Hampshire, Milford 15-minute quadrangle, surficial (C. Koteff, Boston, Mass.)
New Jersey, Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)
New Mexico:
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Midway belt, western part of State (W. S. Parks, w, Nashville)
Texas, coastal plain, geophysical and geological studies (D. H. Earle, Austin)

Utah:
Bingham Canyon district (E. W. Tooker, M)
Canaan Creek quadrangle (H. D. Zeller, c, D)
Canyon Peak quadrangle (W. E. Bowers, c, D)
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Cosa mine bumpy (F. W. Osterwald, w)
Crawford Mountains (W. C. Gere, c, Los Angeles, Calif.)
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Dave Canyon quadrangle (H. D. Zeller, c, D)
Death Ridge quadrangle (H. D. Zeller, c, D)
Gilbert Peak 1 NE quadrangle (E. M. Schell, c, Billings, Mont.)
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Raft River area (R. R. Compton, M)
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Vernal phosphate area (E. M. Schell, c, Billings, Mont.)
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Quantico 15-minute quadrangle (R. B. Mixon, Beltsville, Md.)
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Pacific Northwest, geophysical studies (M. D. Kleinkopf, D)
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Sea ice dynamics (M. F. Meier, w, Tacoma, Wash.)
Water, ice, and energy balance of mountain glaciers, and ice physics (M. F. Meier, w, Tacoma, Wash.)
Alaska, Gulkana and Wolverine glaciers (L. R. Mayo, w, Fairbanks)
Montana, Glacier National Park, Grinnell and Sperry Glaciers (A. Johnson, c, Grand Forks, N. Dak.)

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Wisconsin—Continued
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Mother Lode (S. C. Creasey, M)
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San Juan Mountains:
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Idaho, conglomerates (T. E. Mullens, D)

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North Carolina, southwestern part, reconnaissance (J. W. Whitlow, Beltsville, Md.)
Oregon-Washington, nearshore area (P. D. Snavely, Jr., M)
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Utah:
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Hydraulics, ground water:
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Dielectric behavior of water-bearing sediments (W. O. Smith, C. E. Mongan, w, W)
Mechanics of aquifers--principles of compaction and deformation (J. F. Poland, w, Sacramento, Calif.)
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Aquifer-test reevaluation (E. J. McClelland, w, Sacramento)
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Kansas:
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Gravity flow of water in soils and aquifers, western part of State (R. C. Prill, w, Garden City)

New Mexico:
Effects of detonations (F. C. Koopman, w, Albuquerque)
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Channel capacity, Tuolumne River (J. C. Blodgett, w, Sacramento)
Flood profile on the San Joaquin River (K. W. Lee, w, Sacramento)
Mean annual runoff as related to channel geometry (E. R. Hedman, w, Garden Grove)
Recording channel changes by time-lapse photography (J. R. Beck, w, M)

Channel constrictions:
Bridge-site studies, Alaska (J. M. Childers, w, Anchorage)
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Hydraulic criteria for design of bridges and culverts (C. O. Ming, w, Tuscaloosa, Ala.)
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Flow characteristics:
Alluvial channel flow (C. R. Nordin, Jr., w, Fort Collins, Colo.)
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Dispersion processes in estuaries and rivers (H. B. Fischer, w, University of California, Berkeley)
Effect of temperature on winter runoff (W. D. Simons, w, M)
Mechanics of flow structure and fluid resistance-movable boundary (R. S. McQuivey, w, Fort Collins, Colo.)
Mechanics of fluid resistance (H. J. Tracy, w, Atlanta, Ga.)
Numerical simulation of hydrodynamic phenomena by digital computer (Chintu Lai, w, W)
Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, W)
Vertical-velocity characteristics, Columbia River gaging stations, Washington and Oregon (J. Savini, w, Tacoma, Wash.; G. L. Bodhaine, w, W)
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Time-of-travel studies:
- Indiana (R. E. Hoggatt, w, Indianapolis)
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- New York (H. L. Shindel, w, Albany)

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Hydrologic-data collection and processing:

Channel processes (W. W. Emmett, w, W)
- Data storage, retrieval, and application by digital-computer techniques (C. O. Morgan, w, Lawrence, Kans.)
- Drainage-area determinations:
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  - Kentucky (H. C. Beaber, w, Louisville)
  - Mississippi (J. D. Shell, w, Jackson)
  - New Jersey, for gazetteer of streams (E. G. Miller, W, Trenton, N.J.)

- Hydrologic probability models (W. H. Kirby, w, W)
- Sediment loads in streams—methods used in measurement and analysis (J. V. Skinner, w, Minneapolis, Minn.)
- Statistical inferences (E. J. Gilroy, w, W)
- Water budget of North America (R. L. Nace, w, W)
- Colorado, statistical design of data collection network (R. R. Luckey, w, D)
- Kentucky, inventory of public and industrial water use (R. V. Cushman, w, Louisville)
- Maryland, automation of ground-water records (W. E. Webb, w, Towson)
- New York, Long Island, storage and retrieval of hydrologic data (D. E. Vaupel, w, Mineola)

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Hydrologic Instrumentation:

- Borehole geophysics as applied to geohydrology (W. S. Keys, w, D)
- Development of techniques for measurement of moisture-energy relationships in soils and vegetation (I. S. McQueen, w, D)
- Electronic-equipment development—water (J. E. Eddy, w, W)
- Energy-budget evaporation studies, instruments (C. R. Daum, w, D)
- Instrumentation research—water (H. O. Wires, w, Columbus, Ohio)
- Laboratory research, instruments—water (G. F. Smoot, w, W)
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- California:
  - Acoustic-velocity meter feasibility, Chipps Island (W. Smith, w, M)
  - Specific yield, evaluation of installation methods for nuclear meter access tubes (A. L. Johnson, w, D)

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Hydrology, ground-water:

- Geohydrologic environmental study (J. N. Payne, w, Baton Rouge, La.)
- Geologic structure and fresh ground water in the Gulf Coastal Plain (F. H. Jones, w, Baton Rouge, La.)
- Geophysical survey in Wolverton Creek Valley, Sequoia National Park, Calif. (G. L. Bertoldi, w, Sacramento)
- Hydrogeology of carbonate rocks (V. T. Stringfield, w, V)
- Hydrology of the crystalline-rock system in Southeastern States (H. E. LeGrand, w, Raleigh, N.C.)
- Maryland, underground disposal of liquid wastes in brackish-water formations (E. G. Otton, w, Towson)
- New York:
  - Long Island, hydrologic effects of recharge basins (G. E. Seaborn, w, Mineola)
  - Suffolk County, hydrologic conditions (H. M. Jensen, w, Mineola)
  - Western Long Island, analog model (O. L. Franke, w, Mineola)
  - North Dakota, hydrology of prairie potholes (W. S. Eisenlohr, Jr., w, D)
  - Oregon, basalt aquifers, Hermiston-Orndance area (J. H. Robison, w, Portland)
- Tennessee, limestone aquifers, upper Stones River basin (G. K. Moore, w, Nashville)

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Hydrology, surface-water:

- Lakes and reservoirs: Columbia River basin, optimizing reservoir efficiency (C. H. Swift III, w, Portland, Oreg.)
- Alabama, study of conservation lakes (C. F. Hains, w, Tuscaloosa)
- Arkansas, streamflow, rainfall, and trap efficiency studies (S. R. Kennedy, w, Ft. Smith)
- Florida, statewide lake studies (G. H. Hughes, w, Tallahassee)
- Oregon:
  - Abert Lake and other closed-basin lakes in Oregon, hydrology and geochemistry (A. S. Van Denburgh, w, Carson City, Nev.)
  - Klamath Lake water budget (L. L. Hubbard, w, Portland)
- Utah, past elevations of Great Salt Lake (G. L. Whitaker, w, Salt Lake City)

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Major hydrologic limitations on interregional transfers of water (A. M. Piper, w, M)
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Streams:
- Delaware River basin natural flow (E. G. Miller, w, Trenton, N.J.)
- Alabama, Wragg Swamp Canal Investigation, second phase (J. F. McCain, w, Tuscaloosa)
- Alaska, statewide stream discharge and (or) stage (H. Hulsing, w, Anchorage)
- California: Historical record of streambed changes in southern California (M. W. Busby, w, Garden Grove)
- Santa Ana River, changes in regimen (M. B. Scott, w, Los Angeles)
- Massachusetts, Merrimack River estuary and Millers River, infrared imagery study (J. E. Cotton, w, Boston)
- Mississippi, Pearl River boatway studies (C. P. Humphreys, Jr., w, Jackson)
- Missouri, over-year storage requirements for Missouri streams (J. Skelton, w, Rolla)
- Nevada, small drainage areas, floods (R. D. Lamke, w, Carson City)
- New Hampshire, small streams (C. E. Hale, w, Boston, Mass.)
- Oregon: Aisla River basin, effects of logging on streamflow, sedimentation, and temperature (R. C. Williams, w, Cheyenne, Wyo.; D. D. Harris, w, Portland)
- Tualatin River basin (C. H. Swift III, w, Portland)
- Pennsylvania, Philadelphia area (R. A. Miller, w, Harrisburg)
- Tennessee, water resources of Center Hill Lake region (G. K. Moore, w, Nashville)
- Utah, determination of a basis for estimating mean annual runoff from ungaged areas (E. Butler, w, Salt Lake City)
- Wisconsin: Effects of small impoundments on the interrelationships between aquatic biota and chemical quality of Nederlo Creek (P. A. Kammerer, w, Madison)
- Hydrologic effects of a small reservoir, Nederlo Creek basin (R. S. McLeod, w, Madison)
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Industrial minerals:
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Iron:
- Michigan:
  - Gogebic County, western part (R. G. Schmidt, W)
  - Gogebic Range, eastern (V. A. Trent, W)
  - Negaunee and Palmer quadrangles (J. E. Gafr, D)
  - Western Negaunee quadrangle (L. D. Clark, M)
- Missouri (P. W. Guild, W)

Isotope and nuclear studies:
- Carbon isotope geochemistry of water in Magrothy Formation, Long Island, N.Y. (F. J. Pearson, Jr., w, W)
- Instrument development (F. J. Jurceka, D)
- Isotope ratios in rocks and minerals (I. Friedman, D)
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Isotope and nuclear studies--Continued
- Lead isotope and ore deposits (J. S. Stacey, Jr., w, v)
- Nuclear irradiation (C. M. Bunker, D)
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- Stable isotope and ore genesis (R. O. Rye, D)
- Upper mantle studies (M. Tatsumoto, D)
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Land subsidence:
- California, San Joaquin Valley (J. F. Poland, w, Sacramento)

Lead and zinc:
- Lead isotope and ore deposits (J. S. Stacey, Jr., w, v)
- Ore lead, geochemistry and origin (R. S. Cannon, D)
- Colorado, Rico district (E. T. McKnight, W)
- Tennessee, origin and depositional control of selected deposits (H. Wedow, Jr., Knoxville)
- Utah:
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- Virginia, origin and depositional control of selected zinc deposits (H. Wedow, Jr., Knoxville, Tenn.)
- Wisconsin, lead-zinc (W. S. West, Platteville)

Limnology:
- Interrelations of aquatic ecology and water quality (K. V. Slack, w, M)
- Theoretical study of circulation of lakes (A. Ogata, w, M)
- Thermal and biological characteristics of lakes (R. G. Lipscomb, w, Fort Wayne, Ind.)
- Use of remote sensing in physical limnology (A. M. Sturrock, Jr., w, Salt Lake City, Calif.)
- Indiana, paleoecology of Prety Lake (A. S. Jones, w, Univ. of Indiana, Bloomington)
- New York:
  - Hydrochemistry of Oneida Lake basin (F. J. Pearson, Jr., w, W)
  - Statewide, physical, chemical, and biologic characteristics of lakes (P. E. Greeson, w, Albany)
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Low flow and flow duration:
- Florida, frequency studies (R. C. Heath, w, Ocala)
- Georgia, statewide (R. F. Carter, w, Atlanta)
- Illinois:
  - Frequency analyses (W. D. Mitchell, w, Champaign)
  - Partial-record investigation (W. D. Mitchell, w, Champaign)
  - Saline Branch and Salt Fork basins (D. E. Winget, w, Champaign)
- Indiana, low-flow characteristics (R. E. Hoggert, w, Indianapolis)
- Iowa, frequency studies (H. H. Schwob, w, Iowa City)
- Kansas, seepage flow of streams (M. E. Broeker, w, Lawrence)
- Maryland, flood and low-flow frequency curves and flow duration curves (P. N. Walker, w, Towson)
- Massachusetts (G. K. Wood, w, Boston)
- Missouri, seasonal distribution and base-flow recession (J. Skelton, w, Rolla)
- New Jersey (E. G. Miller, w, Trenton)
- New York, low-flow frequency (O. P. Hunt, w, Albany)
- Texas, low-flow studies of selected streams in Texas—quantity and quality (W. B. Mills, w, Austin)
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Marine geology:
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Gulf of Mexico—Caribbean region (H. L. Berryhill, Jr., Corpus Christi, Tex.)

Pacific island studies (G. Corwin, W)

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Oregon, land-sea transect, Newport (P. D. Snavely, Jr., M)
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Puerto Rico cooperative program (L. E. Garrison, M)
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Marine hydrology:
Maryland, effects of water quality changes on benthos in estuaries (R. L. Cory, J. W. Nauman, w, W)
New Jersey:
Recording of maximum tides (T. G. Ross, w, Trenton)
Tidal stage, discharge and velocity studies (A. C. Leno, w, Trenton)
Washington, influence of industrial and municipal wastes on estuarine and offshore water quality (J. F. Santos, w, Tacoma)
Washington—Oregon, movement of radionuclides in the Columbia River estuary (D. W. Hubbell, w, Portland, Oreg.)

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Mercury:
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California, Coast Range ultramafic rocks (E. H. Bailey, M)

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Southeastern United States (R. A. Laurence, Knoxville, Tenn.)
Yukon—Taiya area, Alaska (A. E. Weissenborn, Spokane, Wash.)
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Zinc deposits, origin and depositional control, Tennessee and Virginia (H. Wedow, Jr., Knoxville, Tenn.)
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Mineralogy and crystallography, experimental:
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Nevada Test Site, geologic effects analysis (F. A. McKeown, D)
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Nuclear explosions, hydrology:
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Hydrology of Amchitka Island Test Site, Alaska (S. W. West, W, D)
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Oil-shale resources of the United States (D. C. Duncan, W)

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Triassic (N. J. Silberling, M)

Radiolaria (K. N. Sachs, Jr., W)

Trilobites, Ordovician (R. J. Ross, Jr., D)

Paleontology, stratigraphic:

Cenozoic:
Coastal plains, Atlantic and Gulf (D. Wilson, W)
Diatoms, Great Plains, nonmarine (G. W. Andrews, W)
Foraminifera, smaller, Pacific Ocean and islands (M. R. Todd, W)

Mollusks:
Atlantic coast, Miocene (T. G. Gibson, W)
Pacific coast, Miocene (W. O. Addicott, M)
Poll ten and spores, Kentucky (R. H. Tschudy, D)

Vertebrates:
Pleistocene (G. E. Lewis, D)
Atlantic coast (F. C. Whitmore, Jr., W)
Pacific coast (C. A. Repenning, M)
Panama Canal Zone (F. C. Whitmore, Jr., W)

Mesozoic:
Pacific coast and Alaska (D. L. Jones, M)

Cretaceous:
Alaska (D. L. Jones, M)
Foraminifera:
Alaska (H. R. Bergquist, W)
Atlantic and Gulf Coastal Plains (H. R. Bergquist, W)
Pacific coast (R. L. Pierce, M)
Gulf coast and Caribbean (N. F. Sohl, W)
Molluscan faunas, Caribbean (N. F. Sohl, W)
Western Interior United States (W. A. Cobban, D)
Jurassic, North America (R. W. Imlay, W)
Triassic, marine faunas and stratigraphy (N. J. Silberling, M)

Paleozoic:
Fusu lline Foraminifera, Nevada (R. C. Douglass, W)
Mississippian biostratigraphy, Alaska (A. K. Armstrong, M)
Onesquethaw Stage (Devonian), stratigraphy and rugose corals (W. A. Oliver, W)
Paleobotany and coal studies, Antarctica (J. M. Schopf, Columbus, Ohio)
Palynology of cores from Naval Petroleum Reserve No. 4 (R. A. Scott, D)
Subsurface rocks, Florida (J. M. Berdan, W)
Type Morrow Series, Washington County, Ark. (L. C. Henbest, W)

Ordovician:
Bryozoans, Kentucky (O. L. Kar kkins, W)
Stratigraphy and brachiopods, Eastern United States (R. B. Neuman, W)
Western United States (R. J. Ross, Jr., D)

Silurian-Devonian:
Coral s, 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)

Paleontology, stratigraphic--Continued

Mississippian:
Coral s, 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)

Pennsylvanian:
Foraminifera:
Alaska (C. A. Repenning, M)

Permian:
Floras, southwestern United States (S. H. Mamsey, W)
Stratigraphy and brachiopods:
Alaska (R. E. Grant, W)
Southwestern United States (R. E. Grant, W)
Upper Paleozoic, Western States (M. Gordon, Jr., W)

Paleontology, vertebrate, systematic:
Artiodactyls, primitive (F. C. Whitmore, Jr., W)
Pleistocene fauna, Big Bone Lick, Ky. (F. C. Whitmore, Jr., W)
Soricidae (C. A. Repenning, M)
Tritylodonts, American (G. E. Lewis, D)

Paleotectonic maps. See Regional studies and compilations.

Pegmatites, South Dakota, Keystone pegmatite area (J. J. Norton, W)

Petroleum and natural gas:
Oil and gas resources of the United States (S. P. Schweinfurth, W)
Organic geochemistry (J. G. Palacas, D)
Principles in petroleum resource estimates (W. W. Miller, D)
Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)

Arizona:
Haystack Mountains (E. A. Merewether, D)
Nava jo Reservation, fuels potential (R. B. O'Sullivan, D)

California:
Eastern Los Angeles basin (J. E. Schoellhamer, M)
Elk Hills (R. J. Lantz, Bakersfield)
Salinas Valley (D. L. Durham, M)

Colorado:
Grand Junction 2-degree quadrangle (W. B. Cashion, D)
Mellen Hill quadrangle (H. L. Cullins, c, D)
Northwestern part, Upper Cretaceous stratigraphy (J. R. Gill, D)
Rangely 7½-minute quadrangle (H. L. Cullins, c, D)
Rangely NE quadrangle (H. L. Cullins, c, D)
Savery quadrangle (C. S. V. Barclay, c, D)

Mississippi, Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)
North Dakota, White Butte 15-minute quadrangle (K. S. Soward, c, Great Falls, Mont.)

Utah:
Canaan Peak quadrangle (W. E. Bowers, c, D)
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Petroleum and natural gas—Continued
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Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
Northeastern part, Upper Cretaceous stratigraphy (J. R. Gill, D)
Straight Cliffs 2 NW quadrangle (H. D. Zeller, c, D)
Upper Valley quadrangle (W. E. Bowers, c, D)
Wyoming:
Browns Hill quadrangle (C. S. V. Barclay, c, D)
LaBarge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)
Lander area phosphate reserve (W. L. Rohrer, c, D)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Reid Canyon quadrangle (W. H. Laraway, c, D)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
Upper Cretaceous regional stratigraphy (J. R. Gill, D)
Lament-Baroil area (M. W. Reynolds, D)

Petrology. See Geochemistry and petrology.

Phosphate:
Phosphoria Formation, stratigraphy and resources (R. A. Gulbrandsen, M)
Southeastern United States, phosphate resources (J. B. Cathcart, D)
Florida, land-pebble phosphate deposits (J. B. Cathcart, D)

Idaho:
Mountain Baird quadrangle (D. A. Jobin, c, D)
Pallisades Dam quadrangle (D. A. Jobin, c, D)
Pallisades Peak quadrangle (D. A. Jobin, c, D)
Pallisades Reservoir quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Red Ridge quadrangle (D. A. Jobin, c, D)
Upper Valley quadrangle (R. L. Rioux, c, W)

Montana, Wise River quadrangle (G. D. Fraser, c, D)

Nevada:
Montello area (G. D. Fraser, c, D)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)

Utah:
Crawford Mountains (W. C. Gere, c, Los Angeles, Calif.)
Gilbert Peak 1 NE quadrangle (J. R. Dyni, c, D)
Jessen Butte quadrangle (J. R. Dyni, c, D)
Morgan quadrangle (T. E. Mullens, c, D)
Ogden 4 NE quadrangle (T. E. Mullens, c, D)
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Vernal phosphate area (E. M. Schell, c, Billings, Mont.)

Wyoming:
Clause Peak quadrangle (M. L. Schroeder, c, D)
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Jackson 7-minute quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Jessen Butte area (E. M. Schell, c, Billings, Mont.)
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Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Pine Creek quadrangle (D. A. Jobin, c, D)
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Plant ecology:
Basic research in vegetation and hydrology (R. S. Sigafos, w, W)
Hydrologic phenomena associated with vegetation changes, Boco Mountain, Colo. (G. C. Lusby, w, D)
Periodic plant-growth phenomena and hydrology (R. L. Phipps, w, W)
Plants as indicators of hydrologic environment (F. A. Branson, w, D)
Vegetation changes in southwestern North America (R. M. Turner, w, Tucson, Ariz.)
See also Evapotranspiration; Geochronology; Limnology.

Potash:
Colorado and Utah, Paradox basin (O. B. Rauge, D)
New Mexico, Carlsbad, potash and other saline deposits (C. L. Jones, M)

Primitive areas. See under Mineral and fuel resources—compilations and topical studies, mineral-resource surveys.

Public and industrial water supplies. See Quality of water; Water resources.

Quality of Water:
Reaeration in open-channel flow (R. E. Rathbun, w, Fort Collins, Colo.)

Alaska:
Quality of water analyses (C. G. Angelo, w, Anchorage)
Sediment analyses (P. J. Still, w, Anchorage)
Statewide stream quality of water and (or) temperature (H. Hulsing, w, Anchorage)
Statewide stream sediment discharge (H. Hulsing, w, Anchorage)

Arkansas, water-quality data study (J. H. Hubble, w, Little Rock)

California:
Effects of waste discharge on ground-water quality, Upper Santa Ana River (G. A. Irwin, w, Garden Grove)
Geochemical reappraisal of ground-water quality in western Fresno County (G. L. Bertoldi, w, Sacramento)
Ground water in Orange County (J. A. Moreland, w, Garden Grove)
Lower Santa Clara River (R. L. Banta, w, Garden Grove)
Mapping base of fresh water in San Joaquin Valley (R. W. Page, C. L. Bertoldi, w, Sacramento)
Nitrogen and phosphorus sources and distribution in Clear Lake (W. D. Silvey, w, Sacramento)
Rapid determination of BOD (J. W. Helms, w, Sacramento)
Sacramento-San Joaquin River delta nutrients (W. D. Silvey, w, Sacramento)
Santa Ana River (R. L. Banta, w, Garden Grove)
Trace elements and ground-water quality, Santa Clara Valley (R. C. Averett, w, M)
### Quality of Water—Continued

**California—Continued**
- Turbidity, northwestern California streams (J. R. Ritter, w, Sacramento)

- Florida:
  - Chemical characteristics of Florida streams (M. I. Kaufman, w, Tallahassee)
  - Hydrology of sanitary land-fill areas (J. W. Stewart, w, Tampa)
  - Nutrient enrichment of Lake Okeechobee (B. F. Joyner, w, Ocala)
  - Selected canals, Broward County (C. B. Sherwood, w, Miami)

- Indiana, saline-water resources (R. A. Pettijohn, w, Indianapolis)

- Kansas:
  - Cedar Bluff Irrigation District (R. B. Leonard, w, Lawrence)
  - South Fork Ninnescah River basin (A. M. Diaz, w, Lawrence)
  - Walnut River basin (R. B. Leonard, w, Lawrence)

- Kentucky:
  - Quality of surface and ground water—statewide inventory (H. C. Beazer, w, Louisville)
  - Saline-water investigations (H. T. Hopkins, w, Louisville)

- Louisiana, mixing characteristics of lower Mississippi River (D. E. Everett, w, Baton Rouge)

- Maryland, extent of brackish water in tidal rivers (S. G. Heidel, w, Towson)

- Nebraska, statistical analysis of surface-water quality (K. A. MacKichan, w, Lincoln)

- Nevada, water-quality distribution (A. S. Van Denburgh, w, Carson City)

- New Jersey:
  - Aeration capacity of streams (O. O. Williams, w, Trenton)
  - Passaic River basin, water-quality and streamflow characteristics (P. W. Anderson, w, Trenton)
  - Raritan River basin, water-quality and streamflow characteristics (P. W. Anderson, w, Trenton)

- New Mexico:
  - Saline-water resources of Capitan (reef) limestone (W. L. Hiss, w, Albuquerque)
  - Tularosa saline water (J. S. McLean, w, Albuquerque)

- New York, Long Island, preliminary evaluation (P. Cohen, w, Mineola)

- North Carolina, chemical quality of surface waters in North Carolina (H. B. Wilder, w, Raleigh)

- Ohio, Ohio River basin, ground water (M. Deutsch, w, Columbus)

- Oklahoma, Keystone Reservoir (R. P. Orth, w, Oklahoma City)

- Oregon, Umpqua River basin, surface water (D. A. Curtis, w, Portland)

- Pennsylvania:
  - Delaware River, chemical characteristics (R. W. Paulson, w, Philadelphia)
  - Effect of physical water quality on sedimentation in the Upper Delaware Bay (F. L. Schaef er, w, Philadelphia)
  - Lehigh River basin, water quality of streams (E. F. McCarren, w, Philadelphia)
  - Monongahela River basin, water quality of streams (E. F. McCarren, w, Philadelphia)

- South Carolina, statewide reconnaissance of streams (T. R. Cummings, w, Columbia)

- Texas:
  - Hubbard Creek basin (L. S. Hughes, w, Austin)
  - Quality of water of Texas bays and estuaries (D. C. Hahl, w, Austin)

- Utah:
  - Chemical changes in Great Salt Lake (R. J. Madison, w, Salt Lake City)
  - Reconnaissance of water-quality characteristics of surface waters in the Bear River basin (K. M. Waddell, w, Salt Lake City)
  - Statewide, quality of ground water (A. H. Handy, w, Salt Lake City)

- Virginia:
  - James River basin, water quality and streamflow characteristics (S. M. Rogers, w, Richmond)
  - Statistical analysis of water-quality records for Virginia (S. M. Rogers, w, Richmond)

- Wyoming:
  - Platte River basin, surface and ground water (S. J. Rucker, w, Worland)
  - Selenium in ground water near Casper, Natrona County (M. A. Crist, w, Cheyenne)

See also Geochemistry, Hydrology, Limnology, Sedimentation, Water resources.

### Quicksilver

See Mercury.

### Radioactive Materials, Transport in Water

- Contamination of ground water by the earth burial of a space nuclear auxiliary power (SNAP) device (D. P. Grove, w, D)

- Disposition of radionuclides, Lower Columbia River (W. L. Haushid, w, Portland, Oreg.)

- Distribution and movement of radionuclides at selected explosion sites (D. B. Grove, w, D)

See also Geochemistry, water.

### Radioactive-Waste Disposal

- Hydrogeologic studies:
  - Hydrologic studies of basalt and related rocks underlying Hanford AEC site, Richland, Wash. (A. M. LaSala, Jr., w, Richland)

- Idaho, National Reactor Testing Station (J. T. Barraclough, w, Idaho Falls)
Radioactive-waste disposal—Continued
Hydrogeologic studies—Continued
New Mexico:
Disposal of treated radioactive-waste effluents, Bandelier Tuff (W. D. Purdy, w, Albuquerque)
Waste-contamination studies, Los Alamos (W. D. Purdy, w, Albuquerque)
South Carolina:
Savannah River Plant (L. W. Marine, w, Columbia)
Savannah River Plant, tank farm hydrology project (W. E. Clark, w, Columbia)
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Rare-earth metals. See Minor elements.
Regional studies and compilations, large areas of the United States.
Basement rock map (R. W. Bayley, M)
Military intelligence studies (M. J. Terman, W)
Paleotectonic-map folios:
Mississippian System (L. C. Craig, D)
Pennsylvaniaian System (E. D. McKee, D)
Remote sensing:
Geologic applications. See under Geophysics, regional.
Hydrologic applications:
Applications to ground-water research (D. A. Phoenix, w, M)
Studies on Delmarva Peninsula, Md. (E. F. Hollyday, w, Towson, Md.)
Study of South Cascade Glacier (M. F. Meier, w, Tacoma, Wash.)
Reservoirs. See Evaporation and Sedimentation, reservoirs.
Rhenium. See Minor elements and Ferro-alloy metals.
Saline minerals:
Colorado, Piceance Basin (D. A. Brobst, D)
Colorado and Utah:
Paradox basin (O. B. Raup, D)
Saline facies of Green River Formation (J. R. Dyni, c, D)
Nevada, Coaldale 30-minute quadrangle area (L. H. Godwin, c, M)
New Mexico, Carlsbad potash and other saline deposits (C. L. Jones, M)
Wyoming, Sweetwater County, Green River Formation (W. C. Culbertson, D)
Saline water:
Artesian water supply in southern Florida (F. W. Meyer, w, Miami)
Availability of fresh and saline ground water in the Rio Grande basin of Colorado, New Mexico, and Texas—A pilot study (T. E. Kelly, L. A. Hershey, B. N. Myers, w, Albuquerque, N. Mex.)
Saline ground water computer applications, Kansas (R. J. Dingman, w, Lawrence)
Saline ground water of the United States (F. A. Kohout, w, W)
Saline water resources and potential use in the Tularosa basin, New Mexico (J. S. McLean, w, Albuquerque)
Water in the central limestone region of St. Croix, U.S. Virgin Islands (T. M. Robison, w, San Juan, P.R.)
Salt water intrusion:
Water-contamination studies, effects of saline fronts in Delaware River estuary on wells adjacent to Delaware River (E. Donsky, w, Trenton, N.J.)
California, Orange County, analog simulation of ground water (W. F. Hardt, w, Garden Grove)
Florida, Dade County and city of Miami (C. B. Sherwood, w, Miami)
Georgia:
Brunswick area (D. O. Gregg, w, Brunswick)
Savannah area (H. B. Counts, w, Atlanta)
Puerto Rico, salinity reconnaissance and monitoring system, south coast (J. R. Díaz, w, San Juan)
Washington, reconnaissance of sea-water encroachment (K. L. Walters, w, Tacoma)
See also Marine hydrology; Quality of water.
Sedimentation:
Columbia River, sediment transport below Pasco, Wash., and tidal-flow hydraulics at Vancouver, Wash. (W. L. Haushild, w, Portland, Oreg.)
General studies of erosion and sedimentation, and evaluation of erosion-control practices (I. T. J. King, w, D)
Measurement of river bedload, rivers near Pine Dale, Wyo. (L. B. Leopold, w, W)
Sources, movement, and distribution of sediment in a small watershed (M. G. Wolman, w, Baltimore, Md.)
Transport properties of natural clays (R. G. Wolff, w, W)
Western States, evaluation and development of methods for classification of arid and semiarid watersheds (L. M. Shown, w, D)
California:
Bolinas Lagoon (J. R. Ritter, w, Sacramento)
Eel River basin, sediment transport (W. M. Brown III, w, M)
Fluvial sediment transport to San Francisco Bay (G. Porterfield, w, Sacramento)
North coastal streams, sediment transport (N. L. Hewley, w, Sacramento)
San Juan Creek (C. G. Kroll, w, Garden Grove)
Sediment characteristics of California streams (B. L. Jones, w, Sacramento)
Sediment transport, Russian River (J. R. Ritter, w, M)
Sedimentation in western tributaries of the Sacramento River (B. L. Jones, w, Sacramento)
Trap efficiency (L. E. Young, w, M)
Use of turbidity records to determine sediment discharge (B. L. Jones, w, Sacramento)
Colorado, Badger Wash area, effect of grazing exclusion (G. C. Lusby, w, D)
Indiana, reconnaissance of sediment yields in streams (R. F. Filtz, w, Columbus, Ohio)
Louisiana, Bayou Lafourche, channel building processes (W. H. Doyle, w, Baton Rouge)
Montana:
Sedimentation in Little Prickly Pear Creek (A. R. Gustafson, w, Worland, Wyo.)
Streamflow, sedimentation, and temperature, Blue-water Creek basin (J. R. Knaptone, w, Helena)
Sedimentation—Continued

New Jersey:

- Changes in sediment yield due to construction of a major highway (L. J. Mansue, w, Trenton)
- Sediment investigations, Delaware River basin (L. J. Mansue, w, Trenton)
- Stony Brook watershed, fluvial sedimentation (L. J. Mansue, w, Trenton)

New Mexico:

- Mechanics of flow and sediment transport in Rio Grande conveyance channel near Bernardo (J. K. Culbertson, w, Albuquerque)
- Reservoir trap efficiency (J. D. Dewey, w, Albuquerque)

North Carolina, preliminary report on sediment in streams (H. E. Reeder, w, Raleigh)

Pennsylvania:

- Bixler Run watershed, hydrology and sedimentation (L. A. Reed, w, Harrisburg)
- Corey Creek and Elk Run watershed (L. A. Reed, w, Harrisburg)
- Evaluation of erosion-control measures used in highway construction (L. A. Reed, w, Harrisburg)
- Susquehanna River basin, fluvial sediment reconnaissance (L. A. Reed, w, Harrisburg)
- Texas coastline, Laguna Madre—Padre Island (H. L. Berryhill, Jr., Corpus Christi, Tex.)

Washington:

- Chehalis River basin, fluvial sediment transport (P. A. Glancy, w, Carson City, Nev.)
- Palouse River basin, fluvial sediment transport (P. R. Boucher, w, Pasco)
- Snohomish River basin, fluvial sediment transport (L. M. Nelson, w, Tacoma)
- Walla Walla River basin, fluvial sediment transport (B. E. Mapes, w, Pasco)

Wisconsin, reconnaissance sediment investigations (S. M. Hindall, w, Madison, Wis.; R. F. Flint, w, Columbus, Ohio)

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Sedimentation, reservoirs:

- California, Dos Rios Reservoir sediment study (J. M. Knott, w, M)
- Georgia, North Fork Broad River, subwatershed 14 near Avalon (R. G. Grantham, w, Atlanta)
- Louisiana, Bayou Dupont watershed, reservoir (R. L. McAvoy, w, Baton Rouge)
- Maryland, North Branch Rock Creek near Rockville (W. J. Davis, w, College Park)
- South Carolina, Lakes Marion and Moultrie (T. R. Cummings, w, Columbia)
- Utah, Paria River basin, Sheep Creek near Tropic sediment barrier (G. C. Lusby, w, D)

Selenium. See Minor elements.

Silver. See Heavy metals.

Soil moisture:

- Effects of depth and duration of floodwater spreading on vegetation in northeast Montana (F. A. Bransor, w, D)
- Hydrologic implications of the physical and chemical characteristics of soils (R. F. Miller, w, G)
- Thermal conductivity of soil, instruments (C. R. Daur, w, D)

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Spectroscopy:

- Mobile spectrographic laboratory (A. P. Marranzino, G)
- Spectrographic analytical services and research (A. W. Helz, w; A. T. Myers, D; H. Bastron, M)
- X-ray spectroscopy (H. J. Rose, Jr., W; H. Bastron, M)

Springs:

- Missouri (A. Homuy, w, Rolla)
- Utah (J. C. Mundorff, w, Salt Lake City)

See also Marine hydrology.

Stratigraphy and sedimentation:

- Alaska Cretaceous (D. L. Jones, M)
- East-coast Continental Shelf and Margin (R. H. Meade, Jr., Woods Hole, Mass.)
- Middle and Late Tertiary history, Northern Rocky Mountains and Great Plains (N. M. Denison, D)
- Paleozoic rocks, Ruby Range, Montana (E. T. Ruppel, D)
- Phosphoria Formation, stratigraphy and resources (R. A. Gulbransen, M)
- Pierre Shale, chemical and physical properties, Montana, North Dakota, South Dakota, Wyoming, and Nebraska (H. A. Tourtelot, D)
- Regional synthesis, Gulf Coastal Plain and Continental Shelf (J. C. Maher, M)
- Sedimentary petrology laboratory (H. A. Tourtelot, D)
- Sedimentary structures, model studies (E. D. McKee, D)
- Southwest basin and range Tertiary stratigraphy, Utah-California-Nevada (F. N. Houser, D)
- Williston basin, Wyoming, Montana, North Dakota, South Dakota (C. A. Sandberg, D)
- Arizona, Hermit and Supai Formations (E. D. McKee, D)
- Colorado:
  - Jurassic stratigraphy (G. N. Pipiringos, D)
  - Upper Cretaceous stratigraphy (J. R. Gill, D)
- Nebraska, central Nebraska basin (G. N. Pipiringos, D)
- Nevada, stratigraphy and composition of the Roberts Mountains Formation (T. E. Mullens, D)
- Oregon-California:
  - Black sands (H. E. Clifton, M)
  - Hydrologic investigations, black sands (P. D. Snavely, Jr., M)
- Utah:
  - Northeastern part, Upper Cretaceous stratigraphy (J. R. Gill, D)
  - Uinta Mountain Group, stratigraphy (C. A. Wallace, M)
- Wyoming:
  - Lamont-Baroli area (M. W. Reynolds, D)
  - South-central part, Jurassic stratigraphy (G. N. Pipiringos, D)
  - Upper Cretaceous, regional stratigraphy (J. R. Gill, D)

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Structural geology and tectonics:
- Deformation research (S. P. Kanizay, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Transcurrent fault analysis, western Great Basin, Nevada-California (R. E. Anderson, D)

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Sulfur:
- Sulfur deposits in the Gulf Coast region (A. J. Bodenlos, W)

Talc:
- Southeastern United States, ultramafic rocks (D. M. Larabee, W)

Temperature studies, water:
- Missouri River, North Dakota (O. A. Crosby, w, Bismarck)
- Thermal loading of reservoirs and streams (G. E. Harbeck, Jr., w, D)
- Upper Delaware River, Pennsylvania-New York-New Jersey (O. O. Williams, w, Trenton, N.J.)
- Illinois, Illinois River temperature observations (C. R. Sieber, w, Champaign)
- North Carolina, surface water, temperature of streams (T. H. Woodard, w, Raleigh)
- Texas, statewide temperature of streams (J. Rawson, w, Austin)
- Washington, stream temperatures (M. R. Collings, w, Tacoma)

See also Evaporation; Limnology; Marine hydrology; Quality of water.

Thorium:
- Colorado, Wet Mountains (Q. D. Singewald, Beltsville, Md.)
- Occurrence in igneous rocks and veins (M. H. Staatz, D)

Titanium:
- Economic geology of rutile (N. Herz, W)
- Economic geology of titanium (N. Herz, W)

Tungsten. See Ferro-alloy metals.

Uranium:
- Resources of radioactive minerals (A. P. Butler, Jr., D)
- Roll-type deposits:
  - Geology and geochemistry (E. N. Harshman, D)
  - Wyoming, Texas (E. N. Harshman, D)
- Uranium-bearing pipes, Colorado Plateau and Black Hills (C. G. Bowies, D)
- Colorado:
  - Cochetopa Creek uranium-thorium area (J. C. Olson, D)
  - Savery quadrangle (C. S. V. Barclay, c, D)
- Idaho, Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
- New Mexico:
  - Acoma area (C. H. Maxwell, D)
  - Ambrosia Lake district (H. C. Granger, D)
  - San Ysidro area Jurassic studies (E. S. Santos, D)
  - Wingate-Thoreau district (C. T. Plerson, D)
- Texas:
  - Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
  - Texas-New Mexico, deposits in Triassic rocks (W. I. Finch, D)
- Washington, Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)

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- Wyoming:
  - Badwater Creek (R. E. Thaden, D)
  - Browns Hill quadrangle (C. S. V. Barclay, c, D)
  - Central part, selected uranium deposits (F. C. Armstrong, Spokane, Wash.)

Urbanology:
- Application of geology to urban planning, research in techniques (C. G. Johnson, D)
- California:
  - Hayward-Calaveras fault zones (D. H. Radbruch, M)
  - Malibu Beach quadrangle (R. F. Yerkes, M)
  - Palo Alto and San Mateo quadrangles (E. H. Fampeyan, M)
  - Point Dume and Triunfo Pass quadrangles (R. H. Campbell, M)
- San Francisco Bay:
  - Marine geology (D. S. McCulloch, M)
- Sediments, engineering-geology studies (D. R. Nichols, M)
- Colorado, Denver metropolitan area (R. M. Lindvall, D)
- District of Columbia, Washington metropolitan area (H. W. Coulter, W)
- Maryland, Washington, D. C., metropolitan area (H. W. Coulter, W)
- Massachusetts, Boston and vicinity (C. A. Kaye, Boston)
- South Dakota, Rapid City area (J. M. Cattermole, D)
- Tennessee, Knoxville area (J. M. Cattermole, D)
- Utah, Salt Lake City and vicinity (R. Van Horn, D)
- Washington, Puget Sound Basin (D. R. Mullineaux, D)

Urban hydrology, urban hydrology data and techniques (W. J. Schneider, w, W)

Urbanization, hydrologic effects:
- Effect on flood flow:
  - Kansas, Wichita area (C. O. Geiger, w, Wichita)
  - Mississippi, Jackson area (B. E. Wasson, w, Jackson)
- Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)
- Effect on stream channels and channel deltae in estuaries, Maryland and Pennsylvania (L. B. Leopold, w, W)
- Effect on stream temperature (E. J. Pluhowski, w, W)
- Effect on water resources (H. P. Guy, w, Fort Collins, Colo.)
- Florida, urban hydrology study, Bay Lake (H. G. Stranglund, w, Winter Park)
- Maryland, sedimentation and hydrology in Ro-K Creek and Anacostia River basins (W. J. Davis, w, College Park)
- Pennsylvania, documentation of pre-urbanization hydrologic conditions (R. A. Miller, w, Harrisburg)

Texas:
- Urban hydrology study, Bryan (P. B. Rohde, Jr., w, Austin)
- Urban hydrology study, San Antonio (E. E. Schroeder, w, Austin)
- Washington, metropolitan Seattle-Tacoma area (F. T. Hidaka, B. L. Foxworthy, w, Tacoma)

Vegetation:
- Elements in organic-rich material (F. N. Ward, D)

See also Plant ecology.
Volcanic-terrane hydrology:
Columbia River Basalt (R. C. Newcomb, w, Portland, Oreg.)
See also Artificial recharge.

Volcanology:
Cauldron and ash-flow studies (R. L. Smith, W)
Pacific coast basalts, geochemistry (K. J. Murata, M)
Submarine volcanic rocks, properties (J. G. Moore, M)
Volcanic ash (R. E. Wilcox, D)
Arizona, San Francisco volcanic field (J. F. McCauley, M)
California, volcanic hazards, Lassen Peak and Mt. Shasta (D. R. Crandell, D)
Colorado, east and central San Juan volcanic field, petrology (P. W. Lipman, D)
Hawaii, Hawaiian Volcano Observatory (H. A. Powers, M)
Idaho, central Snake River Plain, volcanic petrology (H. E. Malde, D)
Montana:
Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)
Wolf Creek area, petrology (R. G. Schmidt, D)
Nevada:
Morey Peak caldera study (W. J. Carr, D)
Paintbrush and Timber Mountain tuffs (P. W. Lipman, D)
New Mexico, Valles Mountains, petrology (R. L. Smith, W)
Oregon, Bend area, volcanics (L. C. Rowan, Flagstaff, Ariz.)
Wyoming, deposition of volcanic ash in the Mowry Shale and Frontier Formation (G. P. Eaton, D)

Water management:
Florida, southeastern part, water-management effects (S. D. Leach, w, Tallahassee)
Maryland system planning studies (D. O'Bryan, w, Towson, Md.)
Tennessee, Memphis area, piezometric mapping aid to management (J. H. Criner, Jr., w, Nashville)
See also Nuclear explosions, hydrology.

Water resources:
Application of aerial photography (W. J. Schneider, w, W)
Delmarva Peninsula, hydrology (E. M. Cushing, w, Tomsen, Md.)
Electrical analog models, Texas, Louisiana, aquifers in Gulf coast area (A. N. Turcan, Jr., w, Baton Rouge, La.)
Georgia, Florida, and South Carolina, study of the principal limestone aquifer (Suwannee Strait, in part) (S. M. Herrick, Atlanta, Ga.)
Kanas--New River basin, West Virginia, Virginia, and North Carolina, ground water (P. W. Johnson, w, Charleston, Va.)
Lower Colorado basin, hydrology (O. J. Loelitz, w, Yuma, Ariz.)
Mississippi River water export study, ground-water availability (E. H. Boswell, w, Jackson, Miss.)
Public domain:
Great basin, influence of hydrology and paleohydrology on design of land use programs (C. T. Snyder, w, M)
Pacific coast region--Water-supply exploration (R. E. Smith, w, M)
Rocky Mountain region, water-supply exploration (N. J. King, w, D)

Water resources--Continued
Public domain--Continued
The public domain--condition and conservation (K. R. Melin, w, D)
Western States, areal hydrology (G. C. Lusby, w, D)
Upper Brazos River basin project, Permian basin program (P. R. Stevens, w, Austin, Tex.)
Alabama (w, Tuscaloosa):
Hydrogeologic study of State (J. G. Newton)
Rapid appraisals of water for industrial development (J. G. Newton)
Relation of oil and gas industry to water resources (W. J. Powell)

Water resources:
Coosa River basin, upper part (J. R. Harkins)
East-central part (L. V. Causey)
Piedmont area (J. C. Scott)
Southwest part (J. R. Avrett)
Tennessee River basin (J. R. Harkins)
Tombligbee-Black Warrior River basin, upper part (J. R. Avrett)
Alaska (w, Anchorage except as noted otherwise):
Ground Water:
Kodiak Island Borough (J. B. Weeks)
National parks (C. Zenone, Anchorage; J. A. McConaghy, Juneau)
Statewide water levels (A. J. Feulner)
Amchitka Island test site (W. C. Ballance)
Anchorage area (W. W. Barnwell)
Greater Juneau Borough (J. A. McConaghy, Juneau)
Kenai Peninsula Borough (S. H. Jones, G. S. Anderson)
Summary of water availability (A. J. Feulner)
American Samoa (M. M. Miller, w, Honolulu, Hawaii)
Arizona (w, Tucson):
Hydrogeologic reconnaissance of lower Tonto Creek basin (H. H. Schumann)

Ground water:
Analysis of water-level declines (E. B. Hodge)
Beardale area (W. Kam)
Big Sandy Valley (W. Kam)
Coconino County, southern part (E. H. McGavock)
Electric-analog analysis of hydrologic data for Avra Valley (O. Moosburner)
Kingman area (J. B. Gillespie)
Navajo Indian Reservation (M. E. Cooley)
Reconnaissance study of water supply of Lake Mead Recreational Area (C. B. Bentley)
Safford area (E. S. Davidson)
Tucson basin (E. S. Davidson)
Hydrology:
Alluvial basins (M. E. Cooley)
Remote sensing--Gila River phreatophyte project (R. C. Culler)

Arkansas (w, Little Rock):
Bayou Bartholomew system study (M. E. Broom)

Ground water:
Bayou Bartholomew study of alluvial valleys of Arkansas and Verdigris Rivers (M. S. Bedinger)
Sparta Sand analog study (J. E. Reed)

Water resources:
Clay, Craighead, Greene, and Poinsett Counties (M. S. Hines)
Water resources--Continued
Arkansas (w, Little Rock)--Continued
Water resources--Continued
Hempstead, Lafayette, Little River, Miller, and Nevada Counties (A. H. Ludwig)
Ozark Plateaus province (A. G. Lamonds)
California (w, Menlo Park, except as noted otherwise):
Ground water:
Antelope Valley (R. M. Floyd, Jr.)
Artificial recharge study, Yucaipa area, San Bernardino County (J. H. Koehler)
China Lake, Naval Ordnance Test Station, continuing inventory (J. H. Koehler)
Cuyama Valley (J. A. Singer)
Death Valley, Texas-Travertine Spring area (G. A. Miller)
Death Valley National Monument, hydrologic reconnaissance (G. A. Miller)
Ground-water inventory, Upper Santa Margarita basin (B. A. Winters, w, Garden Grove)
Harper Valley (W. R. Moyle, Jr.)
Hollister area (Chabot Kilburn)
Indian Wells Valley appraisal (L. C. Dutcher)
Indian Wells Valley hydrologic model (R. M. Floyd, Jr.)
Ivanpah Valley (W. R. Moyle, Jr.)
Madera area (H. T. Mitten)
Mojave River analog model (W. F. Hardt)
San Gorgonio Pass area, appraisal (R. M. Floyd, Jr.)
Santa Barbara County ground-water data (R. E. Lewis)
Santa Clara County, analog model (P. R. Wood)
Tracy-Dos Palos area, San Joaquin Valley (W. R. Hotchkiss, G. O. Balding)
Upper Coachella Valley (S. J. Tyley)
Upper Santa Ana River valley (J. J. French)
Upper Santa Clara River valley, Los Angeles County (S. G. Robson)
Vandenberg Air Force Base, continuing inventory (J. H. Koehler)
Hydrology:
Big Bear Lake (E. G. Pearson)
Cachuma Reservoir (M. W. Busby)
California comprehensive framework study (S. E. Rantz)
Hydrologic bench marks (J. R. Crippen)
Joshua Tree-Yucca Valley (R. E. Lewis)
Perris Valley reconnaissance (M. W. Busby)
Salton Sea reconnaissance (M. W. Busby)
Surface water, temperature of California streams (J. C. Blodgett, Sacramento)
Water resources, Redwoods National Park (J. P. Akers)
Colorado (w, Denver):
Ground water:
Baca and southern Prowers Counties (L. A. Hershey)
Bent County (J. H. Irwin)
High Plains of Colorado (W. E. Hofstra)
Pueblo Army Depot (F. A. Welder)
U.S. Air Force Academy ground-water supply (F. A. Welder)
Water resources--Continued

Georgia (w, Atlanta):
  Ground water, Gordon, Murray, and Whitfield Counties
    (C. W. Cressler)
  Hydrogeology, Pulaski, Wilcox, Crisp, Dooly, Lee, and
    Sumter Counties (R. C. Vorhis)
  River-systems studies (R. F. Carter)
  Statewide special studies (A. M. F. Johnson)
  Water resources:
    Colquitt County (E. A. Zimmerman)
    Liberty County, Riceboro area (G. D. Tasker)
Guam, water resources, Andersen Air Force Base, northern Guam
    (D. A. Davis, w, Honolulu, Hawaii)

Hawaii (w, Honolulu):
  Water resources:
    Hawaii, water-resources reconnaissance summary
      (D. A. Davis)
    Kauai, Waiakaaale, rainfall (M. M. Miller)
    Maui, northeastern Maui, reconnaissance (K. J. Takasaki)
    Maui, Wailuku area, reconnaissance (G. Yamanaga)
    Oahu:
      Pearl Harbor area, discharge-head relationship
        (R. H. Dale)
      Pearl Harbor area, ground-water study
        (R. H. Dale)

Idaho (w, Boise except as noted otherwise):
  Ground water, Kooskia National Fish Hatchery, water supply
    (A. H. Harder, E. G. Crosthwaite)
  Surface water, Bruneau River basin, systems gaging
    (H. C. Riggs, W)

Water resources:
  Bear River basin, Idaho part (N. P. Dion)
  Big Lost River basin (E. G. Crosthwaite, C. A. Thomas)
  Craters of the Moon National Monument, water supply for
    Cottonwood Canyon Campground site (F. F. Norvitch, R. R. Bell)
  Goose Creek-Rock Creek area (E. G. Crosthwaite)
  Little Lost River basin (H. A. Waite, S. O. Decker)
  Mud Lake area (P. R. Stevens)
  Portneuf River basin (R. F. Norvitch, A. L. Larson)
  Raft River basin (E. H. Walker, S. O. Decker)
  Snake Plain aquifer (R. F. Norvitch, C. A. Thomas, R. J. Madison)
  Snake River inflow, Milner to King Hill (C. A. Thomas)

Indiana (w, Indianapolis):
  Analog models:
    Columbus area (F. A. Watkins, Jr.)
    Upper White River basin (R. W. Maclay)
  Ground water:
    Drainage basins tributary to the Ohio River (R. A. Pettjohn)
    Kankakee and Calumet River basins (J. D. Hurn)
    St. Joseph River basin (R. A. Pettjohn)
    Wabash River basin (R. A. Pettjohn)
    Whitewater River basin (R. J. Wolf)
  Upper White River basin (L. W. Cable)

Iowa (w, Iowa City):
  Dakota aquifer appraisal (W. L. Steinhilber)
  Geology and ground-water resources, Cerro Gordo County
    (K. D. Wahl)

Kansas (w, Lawrence):
  Analysis of hydrologic data (J. M. McNellis)
  Electrical analog model studies of areal hydrologic problems
    (J. D. Winslow)
  Streamflow variability (C. V. Burns)

  Ground water:
    Northwestern part (E. D. Jenkins)
    Southwestern part (H. E. McGovern)
    Atchison County (J. R. Ward)
    Doniphan County (C. K. Bayne)
    Finney County (W. R. Meyer)
    Hamilton County (H. E. McGovern)
    Jefferson County (J. D. Winslow)
    Johnson County (H. G. O'Connor)
    Kearny County (H. E. McGovern)
    Montgomery County (H. G. O'Connor)
    Pratt County (D. W. Layton)
    Rush County (J. McNellis)

Water resources, Kansas Valley Abilene to Kansas City (S. W. Fader)

Kentucky (w, Louisville):
  Ground water:
    Hydrology of buried Pennsylvanian channel sandstone
      (R. W. Davis)
    Jackson Purchase area (R. W. Davis)
    Sparta Sand analog study (J. E. Reed)

  Water resources:
    Bowling Green area (T. W. Lambert)
    Mammoth Cave area (R. V. Cushman)

Louisiana (w, Baton Rouge, except as noted otherwise):
  Tangipahoa-Tchefuncte River basins (D. J. Nyman)

  Ground water:
    Avoyelles Parish (J. R. Marie)
    Evangeline and Jasper aquifers, southwest part
      (M. S. Whitfield)
    Gramercy area (C. Kilburn)
    Hydrology of the Red River valley (A. H. Ludwig, Little Rock, Ark.)
    Kisatchie Forest area (J. E. Rogers)
    Morehouse Parish (T. H. Sanford)
    Norco area (R. L. Hosman)
    Sparta Sand analog study (J. E. Reed)

  Surface water, drainage areas (R. Sloss)
  Water resources:
    Amite-Tickfaw River basins (M. D. Winner, Jr.)
    Baton Rouge area (C. D. Whitman, Jr.)
    Little River basin (M. W. Gaydosh)
    New Orleans area (C. D. Whitman, Jr.)
    Plaquemine-White Castle area (C. D. Whiteman, Jr.)
    Public supplies (D. C. Dial)
    Site studies (R. L. Hosman)
    Southwestern part (A. L. Zack)

Maine (w, Augusta):
  Ground water:
    Lower Aroostook basin in Maine (G. C. Prescott)
    Lower Kennebec basin (G. C. Prescott)

Water resources--Continued

Iowa (w, Iowa City)--Continued

Geology and ground-water resources, Linn County
  (R. E. Hansen)

  Ground-water resources of a Mississippian aquifer
    (W. L. Steinhilber)

  Water availability, Muscatine Island, Muscatine County
    (R. E. Hansen)

Water resources Continued

Iowa (w, Iowa City)--Continued

Geology and ground-water resources, Linn County
  (R. E. Hansen)

  Ground-water resources of a Mississippian aquifer
    (W. L. Steinhilber)

  Water availability, Muscatine Island, Muscatine County
    (R. E. Hansen)

Kansas (w, Lawrence):
  Analysis of hydrologic data (J. M. McNellis)
  Electrical analog model studies of areal hydrologic problems
    (J. D. Winslow)
  Streamflow variability (C. V. Burns)

  Ground water:
    Northwestern part (E. D. Jenkins)
    Southwestern part (H. E. McGovern)
    Atchison County (J. R. Ward)
    Doniphan County (C. K. Bayne)
    Finney County (W. R. Meyer)
    Hamilton County (H. E. McGovern)
    Jefferson County (J. D. Winslow)
    Johnson County (H. G. O'Connor)
    Kearny County (H. E. McGovern)
    Montgomery County (H. G. O'Connor)
    Pratt County (D. W. Layton)
    Rush County (J. McNellis)

Water resources, Kansas Valley Abilene to Kansas City (s. W. Fader)

Kentucky (w, Louisville):
  Ground water:
    Hydrology of buried Pennsylvanian channel sandstone
      (R. W. Davis)
    Jackson Purchase area (R. W. Davis)
    Sparta Sand analog study (J. E. Reed)

  Water resources:
    Bowling Green area (T. W. Lambert)
    Mammoth Cave area (R. V. Cushman)

Louisiana (w, Baton Rouge, except as noted otherwise):
  Tangipahoa-Tchefuncte River basins (D. J. Nyman)

  Ground water:
    Avoyelles Parish (J. R. Marie)
    Evangeline and Jasper aquifers, southwest part
      (M. S. Whitfield)
    Gramercy area (C. Kilburn)
    Hydrology of the Red River valley (A. H. Ludwig, Little Rock, Ark.)
    Kisatchie Forest area (J. E. Rogers)
    Morehouse Parish (T. H. Sanford)
    Norco area (R. L. Hosman)
    Sparta Sand analog study (J. E. Reed)

  Surface water, drainage areas (R. Sloss)
  Water resources:
    Amite-Tickfaw River basins (M. D. Winner, Jr.)
    Baton Rouge area (C. D. Whitman, Jr.)
    Little River basin (M. W. Gaydosh)
    New Orleans area (C. D. Whitman, Jr.)
    Plaquemine-White Castle area (C. D. Whiteman, Jr.)
    Public supplies (D. C. Dial)
    Site studies (R. L. Hosman)
    Southwestern part (A. L. Zack)

Maine (w, Augusta):
  Ground water:
    Lower Aroostook basin in Maine (G. C. Prescott)
    Lower Kennebec basin (G. C. Prescott)
Water resources--Continued
Maine (w, Augusta)--Continued
Ground water--Continued
Meduxnekeag and Prestile basins in Maine (G. C. Prescott)
St. John basin in Maine (G. C. Prescott)
Maryland (w, Towson, except as noted otherwise):
Ground water:
Aquifer research in limestone terranes, Frederick and Hagerstown Valleys (L. J. Nutter)
Assateague Island National Seashore (E. F. Hollyday)
Evaluation of Magothy aquifer, Annapolis area (F. K. Mack, w, Annapolis)
Exploration of Salisbury paleochannel (J. M. Weigle)
Sedimentary rocks, occurrence of ground water, coastal plain (H. J. Hansen, w, State employee, Baltimore)
Susquehanna River basin (P. R. Seaber, w, Harrisonburg, Pa.)
Water resources:
Georges Creek basin, a corner of Appalachia (D. O'Bryan, w, W)
Lower Bay counties (Calvert, Charles, and St. Marys) (J. M. Weigle)
Remote sensing on Delmarva Peninsula (E. F. Hollyday)
Massachusetts (w, Boston):
Ground water:
Boston, central area (J. E. Cotton)
Cape Cod National Seashore (J. E. Cotton)
Water resources:
Charles River basin (E. H. Walker)
Deerfield-Roanantic River basins (L. G. Toler)
Neponset-Weymouth River basins (R. A. Brackley)
Taunton River basin (J. R. Williams)
Michigan (w, Lansing):
Hydrology of river-based recreation (G. E. Hendrickson)
Ground water:
Houghton-Keweenaw Counties (G. E. Hendrickson)
Oakland County (F. R. Twenter)
Ontonagon County (G. E. Hendrickson)
Tricounty area (K. E. Vanlier)
Water resources:
Grand River basin (K. E. Vanlier)
Kalamazoo County (J. B. Miller)
River basins in southeastern Michigan (R. L. Knuttila)
Minnesota (w, St. Paul):
Ground water:
Geology and water-bearing characteristics of glacial deposits, northeastern Minnesota (T. C. Winter)
Ground water at St. James (J. O. Helgesen)
Ground water for irrigation near Broten (W. A. Van Voast)
Ground water for irrigation near Little Falls (J. O. Helgesen)
Ground water for irrigation near Perham (H. O. Reeder)
Ground water for irrigation near Wadena (G. F. Lindholm)
Water resources--Continued
Minnesota (w, St. Paul)--Continued
Hydrogeology, Twin Cities metropolitan area (H. O. Reeder)
Hydrologic parameters controlling recreational use of Minnesota rivers (R. F. Brown)
Water budget:
Lake Sallie (W. B. Mann IV)
Shagawa Lake (D. W. Ericson)
Water resources of the Red River of the North basin in Minnesota (T. C. Winter)
Water-resources reconnaissance of watershed units:
Blue Earth River (W. A. Van Voast)
Cottonwood River (W. A. Van Voast)
Crow Wing River (G. F. Lindholm)
Hawk Creek (W. A. Van Voast)
Kettle River (G. F. Lindholm)
Lower St. Croix River (G. F. Lindholm)
Red Lake River (L. E. Bidwell)
Redwood River (W. A. Van Voast)
Snake River (G. F. Lindholm)
Mississippi (w, Jackson):
Ground water, Sparta Sand analog study (J. E. Reed)
Water resources:
Amite, Franklin, Lincoln, Pike, and Wilkinson Counties (R. Newcome)
Clarke, Jasper, Lauderdale, Newton, Scott, and Smith Counties (E. H. Boswell)
Harrison County (D. E. Shattles)
Jackson County (D. E. Shattles)
Kemper, Leake, Neshoba, Noxubee, and Winston Counties (E. H. Boswell)
Natchez Trace Parkway, investigations along (F. H. Thomson)
Washington County (R. E. Taylor)
Missouri (w, Rolla):
Ground water:
Missouri River alluvium (L. F. Emmet)
Sparta Sand analog study (J. E. Reed)
Water resources:
Northeast Missouri (E. E. Gann)
Northwest Missouri (E. E. Gann)
St. Louis, St. Charles, and Jefferson Counties (H. G. Jeffery)
Montana (w, Billings, except as noted otherwise):
Ground water:
Central Powder River valley (W. R. Miller)
Eastern Judith Basin (R. D. Feltis)
Northern Cheyenne Indian Reservation (W. B. Hopkins)
Tobacco and Upper Stillwater River valleys (D. L. Coffin, w, Helena)
Water supplies for national parks, monuments, and recreation areas (R. D. Feltis, w, Billings, and D. L. Coffin, w, Helena)
Wiota-Wolf Point Irrigation Unit (W. B. Hopkins)
Yellowstone River basin, Billings to Park City (A. W. Gosling)
Potential stock-water supply, Garvin Basin (W. B. Hopkins)
Statewide, special investigations (D. L. Coffin, w, Helena)
Water resources--Continued

Nebraska (w, Lincoln):
  Ground water, determination of ground-water withdrawals in Hamilton and York Counties (E. K. Steed)
  Water in Nebraska (R. Bentall)

Water resources:
  Jefferson County (M. D. Veatch)
  Pierce County (C. F. Keech)
  Polk County (C. F. Keech)
  Seward County (M. J. Ellis)

Nevada (w, Carson City):
  Framework study, Great Basin (T. E. Eakin)

Water resources:
  Big Smoky Valley (F. E. Rush and C. V. Schroer)
  Carson River basin (P. A. Glancy)
  Columbus Salt Marsh-Soda Spring Valley area (A. S. Van Denburgh)
  East Walker—Antelope Valley area (P. A. Glancy)
  Paradise Valley (J. R. Harrill, D. O. Moore)
  Truckee River basin (A. S. Van Denburgh)
  Virgin River Valley area (P. A. Glancy)
  Water supply, mining districts (H. A. Schamberger)

New Hampshire (w, Boston, Mass.):
  Ground water:
    Ashuelot River basin (H. A. Whitcomb)
    Middle Merrimack River basin (H. A. Whitcomb)

New Jersey (w, Trenton):
  Geohydrology, Potomac-Raritan-Magothy aquifer system (H. E. Gill)

Ground water:
  Geohydrologic analysis of the Englishtown Formation, New Jersey (W. Kam, W. D. Nichols)
  Water-level fluctuations, 1963-67 (J. H. Nakao)
  Camden County, geology and ground-water resources (E. Donsky)
  Cumberland County (J. G. Rooney)
  Hackensack River basin (L. D. Carswell)
  Passaic County (L. D. Carswell)
  Raritan River basin (J. Vecchioli)
  Union County (B. Nemickas)
  Wharton Tract (E. C. Rhodehamel)

New Mexico (w, Albuquerque):
  Ground water:
    Canoncito Navajo Day School (G. C. Doty)
    Capitan Reef (W. L. Hiss)
    Dulce Canyon (J. W. Shomaker)
    Fort Wingate (J. W. Shomaker)
    Gallup-Tohatchi area (J. B. Cooper)
    Gasbuggy event (J. A. Basler)
    Grant County (F. D. Trauger)
    Harding County (F. D. Trauger)
    Lea County Ogalalla (W. A. Mournant)
    Los Alamos water supply (W. D. Purtyman)
    Malaga Bend area (J. S. Havens)
    McMillan delta area (J. S. Havens)
    Mora County (J. W. Mercer)
    Northern High Plains (E. G. Lappala)
    Rio Grande basin (T. E. Kelly)
    Rio Grande compact (L. J. Reiland)
    Roswell basin, Chaves and Eddy Counties, quantitative analysis of the ground-water system (G. E. Welder)
    Sandia Mountains (F. B. Titus)
    Santa Cruz water conditions (W. D. Purtyman)

Water resources--Continued

New Mexico (w, Albuquerque): Continued
  Ground water--Continued
    Tularosa fresh water (J. S. McLean)
    White Sands Missile Range, ground-water exploration (G. C. Dory)
    White Sands Missile Range, water levels and pumpage (F. E. Busch)
    Alamogordo-Acme, Pecos River J. W. Shomaker)
    Gila River (J. D. Hudson)
    Pojoaque River system (F. D. Trauger)
    San Juan River valley (F. P. Lyford)

New York (w, Albany, except as noted otherwise):
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