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GEOLOGICAL SURVEY RESEARCH 1966

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 550–A

GEOLOGICAL SURVEY RESEARCH 1966

WILLIAM T. PECORA, *Director*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 550

Significant results of investigations for fiscal year 1966, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as Chapters A, B, C, and D

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1966

UNITED STATES DEPARTMENT OF THE INTERIOR
STEWART L. UDALL, Secretary

GEOLOGICAL SURVEY
William T. Pecora, Director

GEOLOGICAL SURVEY RESEARCH 1966

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 550–A

A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal 1966, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping

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FOREWORD

"Geological Survey Research 1966" is the seventh annual review of the economic and scientific work of the U.S. Geological Survey. As in previous years the purpose of the volume is to make available promptly to the public the highlights of Survey investigations. This year the volume consists of 4 chapters (A through D) of Professional Paper 550. Chapter A contains a summary of significant results, and the remaining chapters are made up of collections of short technical papers.

Many of the results summarized in chapter A are discussed in greater detail in the short papers or in reports listed in "Publications in Fiscal Year 1966," beginning on page A265. The tables of contents for chapters B through D are listed on pages A259–A264.

Numerous Federal, State, county, and municipal agencies listed on pages A211–A215 cooperated financially with the Geological Survey during fiscal 1966 and have contributed significantly to the results reported here. They are identified where appropriate in the short technical papers that have appeared in Geological Survey Research and in papers published cooperatively, but generally are not identified in the brief statements in chapter A.

Many individuals on the staff of the Geological Survey have contributed to "Geological Survey Research 1966." Reference is made to only a few. Frank W. Trainer, Water Resources Division, was responsible for organizing and assembling chapter A and for critical review of papers in chapters B–D, assisted by Louis Pavlides, Geologic Division. Marston S. Chase, Publications Division, was in charge of production aspects of the series, assisted by Jesse R. Upperco in technical editing, and William H. Elliott and James R. Hamilton in planning and preparing illustrations.

The volume for next year, "Geological Survey Research 1967," will be published as chapters of Professional Paper 575. Previous volumes are listed below, with their series designations.

Geological Survey Research 1960—Prof. Paper 400

Geological Survey Research 1961—Prof. Paper 424

Geological Survey Research 1962—Prof. Paper 450

Geological Survey Research 1963—Prof. Paper 475

Geological Survey Research 1964—Prof. Paper 501

Geological Survey Research 1965—Prof. Paper 525

William T. Pecora

WILLIAM T. PECORA,
Director.

CONTENTS

ILLUSTRATIONS

NOTE.—References in this publication are in three forms:

W. C. Culbertson (p. B159–B164)

Refers to a short paper published in a chapter of "Geological Survey Research 1966." The letter preceding the page numbers identifies the chapter. The tables of contents for chapters B, C, and D are on p. A259–A264.

D. E. White (r1933)

Refers to a publication released in fiscal year 1966. The number is the acquisition number used in computer compilation of the list of publications for the fiscal year (in the text the prefix "r" has been added to the number to avoid confusion with a date). The list is on p. A265–A320.

Footnotes

Used for those publications that were not released in fiscal year 1966 or that are still in press.

INVESTIGATIONS OF NATURAL RESOURCES

The U.S. Geological Survey was created in 1879 for the purpose of classifying the public lands, and examining the geological structure and mineral and water resources of the Nation. The main responsibilities and objectives have not changed in the intervening years, although the means of meeting them have changed radically. The resources program of the Geological Survey expanded in many directions in 1966 and continues to provide the basis for a large portion of the Survey's research. Primary concerns in the program are with the character and magnitude of the Nation's mineral and water resources, the location and distribution of the resources, the principles and processes involved in their formation, and best management of the resources on the public lands.

MINERAL RESOURCES

The United States requires continuous access to supplies of a great many mineral and organic fuel raw materials to sustain and foster economic growth and to support national security. The Geological Survey has a primary mission to aid in assuring that the Nation can meet these needs expeditiously at lowest cost and with a minimum disruption of the quality of the physical environment.

A constant flow of geologic, geochemical, and geophysical data, principles, and techniques is necessary to maintain an adequate rate of discovery of essential commodities. Geologic research is aimed at the definition and identification of new targets and sources for base and ferrous metals, heavy metals, light metals and industrial minerals, radioactive materials, and organic fuels. Recognition of the short supply, the widening gap between production and consumption, and the limited knowledge of domestic resources of certain metals, including gold, silver, platinum, palladium, osmium, iridium, mercury, tin, bismuth, antimony, and tantalum, led to inception this year of a program on heavy metals, and to the creation of a new Branch of Heavy Metals. The program represents an intensified effort to increase the resource base of these metals. Continued basic and applied geologic, geochemical, and geophysical research have provided solid advances in other commodities in 1966. Among these are: (1) extension of copper deposits in Arizona resulting from structural and stratigraphic interpretations; (2) outlining of a silver exploration target area in the Tonopah-Virginia City, Nev., area through geochemical studies of soils and rocks; (3) identification of potential new sources of sodium minerals and aluminum, closely associated with the oil-shale deposits in the Piceance Basin, Colo.; and (4) discovery of large humate deposits in Florida which may one day be used for the chemical and fertilizer industries.

Assessments of the potential resource base for many areas as well as nationwide for certain commodities have been made during the past year. Reports on the States of Washington and California and for the Appalachian region have been completed or are nearing completion. Appraisal of the mineral-resource potential of Primitive Areas, to aid in decisions on the incorporation of such areas into the Wilderness System, was begun in 1966. Field studies have been completed in nine primitive areas, and reports have been published on five. In the organic fuels field, a summary (U.S. Geol. Survey Circular 523) of the resources and energy potential of oil shale in the United States and other areas of the world was made. A related report (U.S. Geol. Survey Circular 522) appraises the oil, gas, and natural-gas liquid resources of the United States and the world.

Exploration-research activity has aimed at (1) improving analytical methods for "pathfinder" elements useful in geochemical prospecting, (2) perfecting new atomic-absorption instrumental techniques such as those used with the "mercury detector" and "silver snooper," and (3) developing a pickup-truck-mounted "camper" analytical laboratory facility to increase the speed and effectiveness of geochemical prospecting and to provide for the careful field testing of new methods and techniques. The Office of Minerals Exploration, the function of which is to stimulate mineral production by assisting private industry financially in exploring for certain mineral commodities, was transferred to the Geological Survey in July 1965. Thirteen contracts providing government-participation loans were awarded during the year, and three projects were certified as ore discoveries.

RESOURCE COMPILATION

During recent years the U.S. Geological Survey, in collaboration with State and Federal agencies, has prepared mineral- and water-resource reports on a number of States. These reports serve many purposes: they establish an inventory of resource data, they serve as a review of geologic and resource information previously published in the State, they provide brief descriptions of known mineral deposits and correlation of the geologic setting of these deposits to regional geology, and they outline areas that warrant further exploration or study.

RESOURCES OF WASHINGTON

Current knowledge of the mineral resources of Washington has been summarized in a report (U.S. Geol. Survey, r2066) [1] prepared in cooperation with the Washington State Department of Conservation, Division of Mines and Geology, and other agencies. This report points out the relationship of many important deposits of metals and nonmetallic minerals with intrusive igneous rocks. The existence of large low-grade copper and molybdenum deposits in the northern Cascade Mountains and the Okanogan Highlands, and the expanding development of zinc-lead-silver deposits in northeastern Washington, hold considerable promise for additional important discoveries. The large resources of high-alumina clay offer a challenge for greater development of additional ceramic and refractory products. They represent a potential local source of alumina for the aluminum industry that has grown here because of the availability of low-cost hydroelectric power.

RESOURCES OF CALIFORNIA

The gold rush of 1849 started the population explosion in California. Since then the State's mineral resources have continued to be developed to meet the needs of an expanding population. California produces 80 different mineral commodities commercially. Currently it is the leading State for 10 of these, and has ranked among the top 3 States in production of 22 other mineral raw materials in recent years. Current knowledge of the mineral resources of California has recently been compiled in cooperation with the California Division of Mines and Geology and the U.S. Bureau of Mines. The compilation describes known resources and the localities favorable for exploration for gold, mercury, tungsten, copper, and iron as well as other metals. Major resources of boron minerals are identified, some of which have long been known and exploited. These and other nonmetallic resources are considered to be more significant than are the metallic resources. Production of oil and gas provides the largest part of the value of the State's mineral output. The production has been maintained by thorough exploration of the complex geologic structures in the coastal mountains and nearby regions. Major faults have created problems in exploration but also have formed many traps in which hydrocarbons have accumulated.

[1] See note opposite page A1 explaining system used for fiscal year 1966 bibliographic references.

BASE AND FERROUS METALS

LEAD AND ZINC

Sphalerite in barite-bearing breccias in Alabama

Sphalerite has been identified by Helmuth Wedow, Jr., in the upper part of the Knox Dolomite, of Cambrian and Ordovician age, in Bibb County, Ala. The sphalerite occurs in barite-bearing breccias close to the contact of the folded Paleozoic strata of the Appalachian Valley and the overlying coastal-plain sedimentary rocks. This is the southernmost recorded occurrence of zinc minerals in the Knox.

Aeromagnetic anomalies associated with deposits in Wisconsin and Illinois

Geologic interpretation of aeromagnetic maps of the central part of the Upper Mississippi Valley zinc-lead district by A. V. Heyl and E. R. King suggests that Paleozoic sedimentary rocks overlie a Precambrian basement consisting largely of granitic rocks. Locally, plutons that are more mafic occur in the north, and a broad open fold of possibly metasedimentary rocks is in the southern part of the district. The magnetic data indicate the presence of major faults in the basement that coincide with the location of known faults and major folds in the overlying Paleozoic strata, evidently produced by renewed movement in post-Precambrian time. The zinc-lead deposits appear to be associated with magnetically positive areas and with tectonic features.

Lead-zinc mineralization in Grant County, Wis.

Geologic mapping by P. M. Blacet in the southern half of the Lancaster 7½-minute quadrangle, Grant County, Wis., has located lead-zinc mineralization and associated rock alteration here. This suggests that pitch- and flat-ore bodies similar to those that are mined elsewhere in the Upper Mississippi Valley district possibly are also present in this area. Almost no prospect drilling has been done in this part of the Lancaster quadrangle, although favorable host rocks and evidence of base-metal mineralization are widespread.

COPPER

Alluvium-covered fault terrane favorable for copper mineralization in Arizona

In the Pima district, Pima County, Ariz., geologic mapping of ore zones and studies of diamond-drill cores by J. R. Cooper and mining company personnel show that the extensive Mission, Pima, Daisy, and Palo Verde copper ore bodies are in altered and extensively mineralized Permian and Cretaceous(?) sedimentary rocks near a weakly altered and mineralized intrusion of quartz monzonite porphyry. The porphyry is not known elsewhere in this part of the district, but the sedimentary rocks that it intrudes crop out south of Mineral Hill. The distribution and structural relationship of these rocks suggest that the copper deposits are in the same structural zone as the San Xavier lead-zinc mine, but have been offset by a system of faults that trend north to northwest. Faults of this system include the pre-ore East fault at the Mission mine and the post-ore Daisy fault at the east end of Mineral Hill. The Daisy fault brings the mineralized Permian and Cretaceous(?) rocks of the Pima-Daisy mine against barren Paleozoic rocks facing in the opposite direction. According to this interpretation, a relatively unexplored segment of the ore-localizing structural zone may occur beneath the alluvium south of Mineral Hill.

Copper mineralization localized in skarn, Chaffee County, Colo.

According to R. E. Van Alstine, the Ace High and Jack Pot prospects in the Poncha Springs quadrangle, Chaffee County, Colo., explore a gahnite-bearing skarn-like aggregate of anthophyllite, tremolite, actinolite, and additional magnesian silicate minerals partly replaced by magnetite, chalcopyrite, and other copper minerals. The shaft at the prospects is inaccessible, but the deposit appears to be a lenticular mass in metasomatized hornblende gneiss between two north-trending faults that have localized a narrow chalcopyrite-quartz vein and a pegmatite dike. The unaltered gneiss adjacent to the mineralized skarn is fine grained, and consists of hornblende, bytownite, cordierite, and small quantities of biotite, quartz, epidote, and apatite. Magnetite and chalcopyrite in places impregnate the rock-forming silicates as tiny grains or fracture fillings. The magnetite is almost completely altered to limonite and hematite; the chalcopyrite is altered largely to botryoidal and fibrous malachite and small quantities of chalcocite, azurite, chrysocolla, brochantite, and chalcanthite. Although the Ace High and Jack Pot deposit is inactive, it resembles gahnite-bearing copper-zinc deposits, previously regarded as magmatic segregates,[2] [3] which have been productive in nearby mines.

Epigenetic copper mineralization in Nonesuch Shale of Michigan

Work by E. O. Ensign, W. S. White, J. C. Wright, and others has shown that pyrite presumably of syngenetic origin, is the only major sulfide mineral throughout most of the copper-bearing Nonesuch Shale, of late Keweenawan age in northern Michigan. It is more abundant in dark-gray finely laminated shale beds than in more massive lighter gray or reddish beds. In a cupriferous zone at the base of the formation, chalcocite is the principal sulfide and is most abundant in certain persistent dark-gray finely laminated beds. The succession of minerals upward and outward from the center of the cupriferous zone is native copper→bornite→chalcopyrite→pyrite. The bornite and chalcopyrite are confined to a narrow selvage at the margin of the cupriferous zone. This selvage, also marked by the presence of greenockite, transects bedding on a regional scale, and its height above the base of the Nonesuch Shale ranges from less than an inch far from White Pine to more than 50 feet near the center of the deposit. Locally, the height of the selvage is inversely proportional to the thickness of dark-gray finely laminated shale at the base of the formation. This relationship, along with textural evidence, suggests that the pattern of mineral zones represents reaction between syngenetic pyrite and copper introduced from below.

Stratigraphic localization of massive sulfide deposits in Arizona

C. A. Anderson and P. M. Blacet have determined the stratigraphic position of 12 Precambrian massive sulfide deposits in the Yavapai Series. These deposits occur in the northern Bradshaw Mountains and Jerome area in central Arizona (Yavapai County) and have yielded copper, lead, zinc, gold, and silver. Nine deposits are in the foliated Alder Group and three are in

[2] Waldemar Lindgren, 1908, Notes on copper deposits in Chaffee, Fremont, and Jefferson Counties, Colorado: U.S. Geol. Survey Bull. 340, p. 157–174.

[3] See note opposite page A1 explaining system used for footnote references.

the less foliated Ash Creek Group. Three of the deposits in the Alder Group are in the Spud Mountain Volcanics, including the Bighampton and Copper Queen deposits in the older breccia facies and the Iron King deposit in the younger andesitic tuffaceous facies. The remaining deposits in the Alder Group are all in the Iron King Volcanics, a thick sequence of pillow and amygdaloidal basalts containing intertongues of rhyolitic rocks. Two of these deposits, the Blue Bell and the DeSoto, are in the lower part of the pillow-lava sequence, whereas the others, consisting of the Lone Pine, Boggs, Iron Queen, and Hackberry deposits, are in the keel of the major syncline developed in the Iron King Volcanics. Two of the deposits in the Ash Creek Group are at Jerome, one of which, the United Verde deposit, is in the lower part of the Grapevine Gulch Formation and associated quartz porphyry, and the other, the United Verde Extension deposit, is in underlying Deception Rhyolite, which is also associated with the quartz porphyry. The third deposit in the Ash Creek Group is in the Shea Basalt, which is stratigraphically below the Deception Rhyolite and has been opened by the Copper Chief mine south of Jerome.

IRON

Magnetic survey outlines iron-formation in Marquette district, Michigan

In the Palmer quadrangle, a ground magnetic survey by J. E. Gair has outlined an anomaly over iron-formation and also has helped to define the structure at the east end of the Palmer basin. The anomaly is about 2,400 feet long, as much as 1,000 feet wide, and has a maximum amplitude of about 27,000 gammas above background. The anomaly is shown roughly on an aeromagnetic map by J. E. Case and J. E. Gair [4] but was not recognized previously and had not been tested by drilling.

Magnetite-bearing pyroxenite found in Iliamna region, Alaska

Magnetite-bearing pyroxenite has been discovered near Frying Pan Lake in the Iliamna D–7 quadrangle, about 250 miles southwest of Anchorage, by R. L. Detterman and B. L. Read. This discovery extends the area of magnetite occurrences about 50 miles west of those staked in 1964 in the eastern part of the Iliamna 1:250,000-scale quadrangle. Chemical and semiquantitative spectrographic analyses of 16 samples gave the following results: 16–24 percent FeO; 1.3 percent TiO_2; and 0.1–3.2 percent P_2O_5. Magnetic fractions of the same samples contained 56–80 percent FeO and about 3.1 percent TiO_2.

[4] J. E. Case and J. E. Gair, 1965, Aeromagnetic map of parts of Marquette, Dickinson, Baraga, Algar and Schoolcraft Counties, Michigan, and its geologic interpretation: U.S. Geol. Survey Geophys. Inv. Map GP 467.

ILMENITE AND ZIRCON

Precambrian placers in Cocke County, Tenn.

Precambrian placers in the Snowbird Group of the Ocoee Series on Snowbird Mountain are reported by R. H. Carpenter, Helmuth Wedow, Jr., and S. W. Maher to contain possibly commercial quantities of ilmenite and zircon. Laminated sandstones contain 30–60 percent heavy minerals, of which ilmenite and zircon make up 90 percent. The ratio of ilmenite to zircon is 6:1. Most of the deposits can be detected on the ground by scintillometer and magnetometer.

HEAVY METALS

GOLD

Gold-bearing conglomerates in northwestern Wyoming

J. D. Love and J. C. Antweiler are continuing their investigation of the source, stratigraphic distribution, areal extent, and geochemistry of finely divided gold in Cretaceous, Paleocene, and younger conglomeratic strata and alluvial deposits in northwestern Wyoming. The following lithologic units were studied:

Lithologic unit	*Age*	*Lithology*
Quaternary sediments.	------------	Gravel, sand, silt.
Conglomerate south of Pass Peak.	Middle(?) Eocene.	Conglomerate and sandstone.
Wind River Formation.	Early Eocene.	Sandstone and quartzite conglomerate.
Pinyon Conglomerate.	Paleocene---	Quartzite conglomerate, coal, sandstone.
Fort Union Formation.	Paleocene---	Quartzite conglomerate and sandstone.
Harebell Formation--	Late Cretaceous.	Quartzite conglomerate, sandstone, and siltstone.

Gold occurs through a stratigraphic interval of at least 1,000 feet of the Harebell Formation, more than 1,500 feet of the Pinyon Conglomerate, and in lesser thicknesses of other strata. It is most abundant in matrix of conglomerate and in sandstone but has been found within quartzite pebbles and in coal, siltstone, and shale. The areal extent of the gold-bearing part of the Harebell Formation in Jackson Hole is probably more than 100 square miles, of the Pinyon Conglomerate 200 square miles, and of other formations much less. Gold-bearing conglomerates in the Fort Union Formation of the Bighorn basin probably were once laterally continuous with those in the Pinyon.

The original major source of gold (suggested by its presence in Precambrian and possibly Paleozoic quartzite fragments and by its typical association with quartzite conglomerate), as well as of the conglomerate itself, is believed to have been a now-buried uplift northwest of the Teton Range. Some of the gold may, however, be related to younger volcanism. The abnormally high gold values in the Wind River Formation suggest the possibility of a third, still unknown source.

Locally secondary concentrations of gold have been recognized. As the number of reliable analyses of geologically controlled samples increases, guides to these concentrations can probably be developed.

Results of 1,093 analyses of gold are as follows:

Lithologic unit	No. of localities	No. of samples	Gold (ppb)[1]	
			Average of all samples	Maximum in random sample
Quaternary sediments	12	176	76	2,000
Conglomerate south of Pass Peak	1	24	31	250
Wind River Formation	3	48	230	2,000
Pinyon Conglomerate	17	665	84	8,700
Fort Union Formation	2	39	76	300
Harebell Formation	5	141	65	1,000

[1] To convert approximately from ppb to dollars per ton, multiply by 0.001.

MERCURY

Possible concealed mercury deposits in Yellow Pine district, Idaho

B. F. Leonard reports that two cirques south and southwest of the east fork of Cinnabar Creek are geologically favorable for the discovery of concealed mercury deposits. The cirques are underlain by the same block-faulted metamorphic and plutonic rocks that in the Hermes (Cinnabar)-Fern area contain mercury deposits. However, the cirques are mantled with glacial debris, creeping talus, snowslide debris, lingering snowbanks, and stunted conifers that effectively conceal the bedrock, and little prospecting has been done. Geochemical prospecting may be suitable here, whereas test-pitting or bulldozing probably would be ineffectual.

SILVER AND MERCURY

Soil samples reflect silver mineralization in Utah and Nevada

Areas of known silver mineralization at Silver Reef, Utah, are clearly indicated by anomalous content of silver and mercury in the soils of these areas, according to H. R. Cornwall and H. K. Stager. Silver and mercury soil anomalies in the Tonopah and Virginia City districts, Nevada, also indicate several promising areas for exploration.

SILVER AND GOLD

Black calcite associated with silver mineralization in southwestern United States

Continuing field and laboratory investigations by D. F. Hewett and A. S. Radtke have shown that manganiferous "black calcite" is present in veins of manganese oxides that cut layered volcanic rocks of Tertiary age in the southwestern United States, and is also a common constituent of silver-bearing manganese oxide ores that locally replace carbonate rocks in the same general region. Samples of black calcite from the old silver-producing districts of Hamilton, Nev., and Ophir, Utah, both yield residues containing from 200 to 1,500 ounces of silver per ton. The silver in the Hamilton material is present as three distinct hypogene minerals, possibly silver-bearing manganates, which are currently being studied by use of the electron microprobe.

Silver and gold in waste sulfide concentrates, Big Creek, Idaho

Sulfide concentrates produced as waste in the recovery of a high-grade huebnerite-scheelite concentrate at the mill of the McRae Tungsten Corp., Big Creek, central Idaho, have been found by B. F. Leonard, C. W. Mead, and Nancy Conklin to contain 110 to 315 troy ounces of silver per ton and 2.8 to 4.1 ounces of gold in addition to a few percent each of copper, lead, and zinc. Only 1 ton of these concentrates was produced per year during tungsten mining operations, and the mining company did not think this small amount worth marketing. However, these concentrates represent silicified zones of considerable size containing widespread, sparsely disseminated sulfide minerals; these large zones merit attention as potential resources of gold and silver.

LIGHT METALS AND INDUSTRIAL MINERALS

ZEOLITES

Zeolites and potash feldspar in California

A study of altered rhyolitic vitric tuffs in the Barstow Formation of middle and late Miocene age in San Bernardino County, Calif., by R. A. Sheppard and A. J. Gude 3d (r1608) resulted in the discovery of beds of secondary potash feldspar that may be of economic value. They also found zeolites and potash feldspar, along with searlesite, in rhyolitic vitric tuff beds interbedded with clastic deposits of Pleistocene Lake Tecopa, Inyo County, Calif. The zeolites are chiefly phillipsite, clinoptilolite, erionite, and trace amounts of chabazite; they generally occupy a zone that is surrounded by unaltered glass. Petrographic evidence and field relations suggest that the zeolites formed diagenetically by alteration of glass. The zeolite zone itself surrounds a zone containing potash feldspar and searlesite, and petrographic evidence in this zone suggests that potash feldspar and searlesite formed by diagenetic alteration of the secondary zeolites. The zonation is thought to be due to chemical variation in the composition of the sediment pore water; this, in turn was inherited from a pattern that existed in the water of the Pleistocene lake, namely, an area of relatively fresh water along the shore that graded basinward into concentric zones of increased alkalinity and salinity.

Zeolites in shattered quartz monzonite in Colorado

The discovery of abnormal concentrations of the zeolite laumontite in large masses of shattered quartz monzonite is a byproduct of a study of beryllium near Mount Princeton, Colo., by W. N. Sharp. Faulting related to structural development of the Arkansas Valley caused shattering of large masses of crystalline rocks and provided conduits for rising solutions that produced the zeolite.

SALINE MINERALS

Salinity gradients help reconstruct history of Paradox basin, Utah and Colorado

Continuing studies of the bromine content of halite beds in the Paradox Member of the Pennsylvanian Hermosa Formation, by O. B. Raup (r0769), support the earlier suggestion that knowledge of the bromine distribution throughout the entire Paradox basin would yield much information about lateral as well as vertical changes in the sedimentary sequence. Together with R. J. Hite, he has continued to assemble data on bromine profiles from stratigraphically equivalent beds of halite that make it possible to define salinity gradients in the basin and thus define areas of high and low salinity. This helps reconstruct the paleogeography and paleotectonic history of the basin throughout periods favorable for salt deposition, and might point to localities and to horizons worthy of further exploration for oil and potash.

Saline deposits at Searles Valley, Calif., record climatic lake fluctuations

Nonmarine saline deposits of late Quaternary age, buried near the middle of Searles Valley, Calif., grade laterally into outcrops of alluvial layers interbedded with calcareous silts and sands deposited in large lakes. G. I. Smith (r0210, r0772) finds that these deposits provide a detailed record of climatically controlled lake fluctuations. Furthermore, the saline-mineral assemblages suggest that the prevailing climates of some interpluvial periods differed from those of other periods in their seasonal distribution of precipitation; some saline layers formed during intervals that had dry winters and wet summers, whereas others formed during periods of wet winters and dry summers. Clues have also been noted in the outcropping sediments that suggest high salinities in the depositing lakes, thus indicating a favorable environment for saline deposition. In Searles Valley, for example, such conditions are implied by the distribution of fresh-water fossils, the presence of certain soluble salts, and the distribution of aragonite. The mineralogy and lithology of drill cores from areas that surround the saline bodies provide additional clues not obtainable from exposed and weathered sections. Such information might aid in identifying other basins containing valuable saline deposits.

Trona from nonmarine saline deposits of Wyoming

Two companies now mine trona from the nonmarine saline deposits in the Wilkins Peak Member of the Eocene Green River Formation, southwestern Wyoming, and four other companies are actively exploring or developing property in the area. The deposits have been studied by W. C. Culbertson (p. B159–B161),[5] who estimates that beds in the area contain 67 billion tons of trona in 24 beds more than 3 feet thick, and 36 billion tons of mixed trona and halite in 14 beds more than 3 feet thick.

Saline facies rocks recognized within oil shales of Colorado

Core-hole data from the Piceance Creek basin of northwest Colorado have disclosed a well-developed saline facies within the rich oil shales in the lower part of the Parachute Creek Member of the Eocene Green River Formation. Studies by J. R. Dyni and R. J. Hite show that cyclic units of nahcolite and halite are interbedded with oil shale in a zone at least 900 feet thick in the depositional center of the basin. The mineral dawsonite is disseminated through the oil shale of this zone. Minor accessory saline minerals include northupite, searlesite, shortite, trona(?), and wegscheiderite. Soda ash from the nahcolite and aluminum from the dawsonite are of potential economic

[5] See note opposite page A1 explaining system used for bibliographic references to other chapters of Professional Paper 550.

value, perhaps as byproducts from spent shale of shale-oil retorts.

Nahcolite ($NaHCO_3$) occurs throughout the saline facies in bedded units as much as 11 feet thick, in layers of a honeycomblike intergrowth of oil shale and nahcolite, and in nonbedded discrete crystalline masses or pods. Nahcolite, which is water soluble, contains 63 percent soda ash by weight. Select intervals of rich oil shale as much as 230 feet thick may average as much as 18 percent nahcolite.

Dawsonite [$NaAl(CO_3)(OH)_2$] has been found in only a few localities in the world, and its abundance in the Piceance Creek basin attests to the unique nature of the geologic environment. The solubility of dawsonite in dilute acid encourages the hope that aluminum can be extracted from it economically. A select section of dawsonitic oil shale, nearly 300 feet thick, averages 12.3 percent dawsonite. The full thickness and areal extent of the dawsonitic oil shale are unknown, but indications are that the size is large in comparison with the small bauxite reserves of the United States. Furthermore, the existence of dawsonite in this locality opens up the possibility that it can also be found in other oil-shale basins containing saline minerals, such as the Uinta basin of Utah and the Green River basin of Wyoming.

PHOSPHATE

Miocene-age phosphate in southwestern Florida

J. B. Cathcart has noted that recent drilling in Hardee, Manatee, and De Soto Counties, to the south of Florida's main land-pebble district, indicates that the phosphate is mostly in the Miocene Hawthorn Formation. The rocks in this area are characteristically low in P_2O_5 content, and the principal diluent is a carbonate mineral. In the western part of this area, in Manatee County, the lower phosphorite unit of the Pliocene Bone Valley Formation is generally missing, probably because it was not deposited. In the southern part, in southern Hardee County, there is a facies change, and the phosphate rocks grade into a southward-thickening shell bed of possible late Miocene age. Aluminum phosphate minerals characterize part of the phosphate zone over much of this part of Florida, but X-ray diffraction studies show that they are missing in southern Hardee County, apparently because leaching by acid ground water did not take place.

Geologic features of phosphate deposits in northern Florida and southern Georgia

Phosphate deposits similar in some ways to those of southern Florida, occur in northern Florida and southern Georgia. Here the deposits consist chiefly of carbonate fluorapatite, and are partly of residual origin (as in rocks of the Hawthorn Formation) and partly of reworked origin (as in rocks of post-Hawthorn age). They also have a leached zone that is characterized by aluminum phosphate minerals although preliminary study by J. B. Cathcart indicates that this leached zone is not as widespread or well developed in the north Florida–south Georgia area as it is in the main land-pebble district of south Florida. The north Florida–south Georgia deposits differ from the south Florida deposits in that they generally lie in basins on the flanks of small anticlines or domes and are composed of finer grained (less than 1 mm) phosphatic material. According to preliminary work they have quartz as the principal diluent, although an iron oxide mineral and pyrite are present also in the brown and black phosphate nodules.

Phosphate deposits of possible economic importance in Iowa

C. E. Brown has sampled the phosphate-bearing basal beds of the Maquoketa Shale, of Late Ordovician age, in northeastern Iowa and found them to contain distinct beds of silty, friable phosphorite of possible economic importance (p. B152–B158). Near Dubuque, the phosphorites average about 2 feet in thickness and contain about 15 percent P_2O_5. Preliminary estimates indicate that nearly 5,000 tons of this phosphate rock per acre are present here. In Clayton County, to the northwest, phosphorites at this horizon are 1 to 2 feet thick and contain 20 to 25 percent P_2O_5. Associated with the phosphorite is fluorite, the first found in the upper Mississippi Valley lead-zinc district; the fluorite is in crystal-lined vugs, where it is associated with calcite, pyrite, and sphalerite.

Precambrian phosphorite in Montana and Tennessee

Precambrian phosphorites are relatively rare, but two occurrences have been recently reported. One of these, a thin bed of phosphorite found by R. A. Gulbrandsen (p. D199–D202) in rocks of the Belt Series near Wolf Creek, Mont., may contain fossils; a structure observed in thin section is strikingly similar to a sponge spicule. The second occurrence, reported by Helmuth Wedow, Jr., R. H. Carpenter, and J. R. Lehr (r2064), is in the Precambrian Ocoee Series at the East Fork manganese district, Sevier County, Tenn. It occurs in a zone of phosphatic arkose and nodular carbonaceous shale at least 6,000 feet long and as much as 100 feet thick. Individual beds of arkosic phosphorite and phosphate nodules contain 25 to 35 percent P_2O_5. One bed of arkosic phosphorite is about 1,200 feet long and as much as 4 feet thick. These discoveries show that environments favorable for phosphate precipitation existed in some areas during Precambrian time.

CLAY

Importance of kaolinite content of Maryland clays

Numerous X-ray diffraction analyses of the fine-grained fractions of samples from the Miocene Chesapeake Group of southern Maryland by M. M. Knechtel and J. W. Hosterman, show that the clay materials of the Choptank and Calvert Formations are made up of montmorillonite and illite in approximately equal amounts, and the samples from the St. Marys Formation contain montmorillonite, illite, and kaolinite also in approximately equal amounts. The absence or near absence of kaolinite in the samples from the Choptank and Calvert strata may be largely responsible for their unsatisfactory firing behavior in bloating tests; the samples from the St. Marys Formation are more satisfactory, and not only form products suited to use as lightweight aggregate, but also appear to be usable as raw materials for the manufacture of common brick.

Potential source of brick clay in Beltsville area, Maryland

C. F. Withington reports (p. D203–D208) that bricks have been made in the laboratory from silty clay tailings in sediment catchment ponds of gravel-washing plants near Beltsville, Md. The composition of this tailings-pond clay compares favorably with raw material now being used commercially for common brick. Additional tests are needed, however, to prove the commercial feasibility of this waste clay as a raw-material resource for brick manufacture.

Geologic setting and mineralogy of clays in Pennsylvania studied

In Pennsylvania, the geologic setting and mineralogy of four white kaolin clay deposits of residual origin are being studied by J. W. Hosterman. The Toland clay, in Cumberland County, south-central Pennsylvania, is derived from phyllite present near the contact of the Antietam Quartzite of Cambrian age. The clay, composed of well-crystallized kaolinite, is being mined for use in cement, but beneficiation would probably make it suitable as a paper filler or paper coater. The Kunkletown clay, from Monroe County, in the eastern part of the State, is derived from Willard's Buttermilk Falls Limestone and the Keyser Limestone, of Devonian and Silurian ages. This clay, used in making white cement, is highly siliceous but does contain well-crystallized kaolinite. The Stormstown and Oreminea deposits, Centre and Blair Counties, central Pennsylvania, are derived from the Gatesburg Formation of Cambrian age. The clay in both deposits, used in making refractory clay products, is highly siliceous but contains a large amount of well-crystallized kaolinite that could be used as a paper filler if beneficiated.

Early uses of sand and clay in North Carolina

A byproduct of clay studies in the southeastern United States was the confirmation by S. H. Patterson that fragments of brick and "mortar" provided by the National Park Service from the Fort Raleigh, N.C., archaeological excavations were made from nearby deposits of sand and clay. This material was manufactured in 1585 or 1586 by the first English-speaking settlers in North America. Fragments of tile from the same site were found to be composed of different material.

BERYLLIUM

Modal analyses of Colorado beryllium-bearing pegmatites

As part of a study of beryl in pegmatites, visually estimated modes published by Staatz and Trites[6] and by Thurston[7] of 3,104 pegmatites of the Quartz Creek and Crystal Mountain pegmatite districts, Gunnison and Larimer Counties, Colo., were compiled by J. J. Norton[8] on ternary diagrams representing the contents of quartz, plagioclase (mostly An_1 to An_6), and perthite. The modes of homogeneous pegmatites of the Crystal Mountain district have a well-defined maximum at 20 percent quartz, 30 percent plagioclase, and 50 percent perthite. Homogeneous pegmatites of the Quartz Creek district also ordinarily have about 20 percent quartz but a wide range in the amounts of plagioclase and perthite; layered pegmatites in this district have similar bulk compositions, but the plagioclase of these pegmatites is concentrated in footwall layers and the perthite in hanging-wall layers.

Beryllium mineralization evaluated in Arizona, New Mexico, and Utah

Large areas characterized by fluorspar deposits and beryllium- and fluorine-rich igneous rocks in southeastern Arizona and southwestern New Mexico are thought by D. R. Shawe to be favorable for the occurrence of beryllium deposits of the Spor Mountain type. Two such areas are described by Shawe (p. C206–C213); a third, recognized later, is in southwestern Utah. It lies about 100 miles south of the Spor Mountain deposit and extends from the southern

[6] M. H. Staatz and A. F. Trites, Jr., 1955, Geology of the Quartz Creek pegmatite district, Gunnison County, Colo.: U.S. Geol. Survey Prof. Paper 265, 111 p.

[7] W. R. Thurston, 1955, Pegmatites of the Crystal Mountain district, Larimer County, Colorado: U.S. Geol. Survey Bull. 1011, 185 p.

[8] J. J. Norton, in press, Ternary diagrams of the quartz-feldspar content of pegmatite in Colorado: U.S. Geol. Survey Bull. 1241–D.

Wah Wah Mountains east-northeast to the vicinity of Marysvale, Utah. The area is characterized by silicic volcanic rocks with unusually high beryllium content (10–50 ppm of Be), topaz-bearing rhyolite associated with thick sections of volcanic rocks, and numerous fluorspar deposits; actual known occurrences of beryllium minerals, though, are sparse.

Vertical tectonics control localization of hydrothermal beryllium deposits in western North America

Studies of the regional distribution of minor elements by W. R. Griffitts, on which D. R. Shawe's conclusions (above) were partly based, have lead Griffitts to conclude that, in western North America, hydrothermal beryllium deposits are largely restricted to areas in which vertical tectonic movements have been dominant. Most such deposits are in the Basin and Range province, but beryllium minerals are also found in some of the volcanic fields that outline the southern half of the Colorado Plateaus province and near grabens in the central and northern Rocky Mountains.

MICA

Fracture control of mica pegmatite emplacement in North Carolina

Mapping by F. G. Lesure in the southern half of the Franklin quadrangle, Macon County, N.C., has shown that numerous small mica pegmatite bodies occur in fractures and shears along the margins or within larger lenticular masses of hornblende-feldspar gneiss. During the last period of regional metamorphism, hornblende gneiss apparently fractured more readily than the adjacent quartz-feldspar and garnet-biotite-sillimanite gneisses. The hornblendic rocks form sills and possibly dikes in the other metamorphic rocks. Semiquantitative analyses of fresh hornblende gneiss and saprolite derived from hornblende gneiss show a range in Ni content of 30–2000 parts per million, and in Cr content of 200–1500 ppm. Such high values suggest a mafic or even ultramafic igneous origin for the hornblende gneiss in this area.

RADIOACTIVE MINERALS

URANIUM

Concentric zonation in uranium-vanadium deposits of San Juan County, Utah

The largest and most productive uranium-vanadium deposits of the Montezuma Canyon area, San Juan County, Utah, are in middle Montezuma Canyon (L. C. Huff and F. G. Lesure, r1542). They are in the Salt Wash Sandstone Member of the Morrison Formation of Jurassic age, and generally occur near the edges of a prominent sinuous and asymmetric compound lens of light-gray to white sandstone nearly a mile wide. Many individual deposits in the area normally are concentrically zoned. The zones (most easily recognized in small deposits) consist of (1) an inner zone of brown, iron-stained nonmineralized rock, (2) an intermediate zone of olive-gray mineralized rock ranging from ¼ to 2 feet in thickness, and (3) an enveloping gray, carbonate-cemented outer zone, which grades into barren country rock. Where the zones cut across the beds at the margins of the deposits they form the characteristic ore rolls of the Colorado Plateau.

Uranium deposits in lignite of North and South Dakota

The results of a comprehensive study of the geologic setting of uranium-bearing lignite in the southwestern part of the Williston basin, North and South Dakota, by N. M. Denson and J. R. Gill[9] show that deposits containing at least 0.1 percent U_3O_8 are confined to the Fort Union Formation of Paleocene age. They occur in a northerly trending belt of deposits 150 miles long that is generally alined with the structurally lowest part of the basin. The rocks containing the deposits are characteristically lenticular. The principal structural and stratigraphic controls for the deposits are shallow troughs superimposed on the flanks of the basin by late Tertiary tectonic movements and the proximity to the pre-Oligocene erosion surface. Uranium, along with arsenic, molybdenum, selenium, and vanadium have been introduced into lignite and other carbonaceous rocks by ground water from Miocene time to the present.

The stratigraphic distribution and characteristics of uranium deposits in lignite and carbonaceous siltstone in the Cave Hills area, Harding County, S. Dak., were described by G. N. Pipiringos, W. A. Chisholm, and R. C. Kepferle.[10] A close coincidence is shown between uranium deposits and the principal aquifers in this region. The study indicates that the uranium content of the coaly rocks decreases progressively downward in the stratigraphic section.

Localization of uranium-bearing veins in Western United States

The structural setting of uranium-bearing veins is reviewed by F. W. Osterwald[11] in the last report of a

[9] N. M. Denson and J. R. Gill, 1965, Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston basin—a regional study: U.S. Geol. Survey Prof. Paper 463, 75 p.
[10] G. N. Pipiringos, W. A. Chisholm, and R. C. Kepferle, 1965, Geology and uranium deposits in the Cave Hills area, Harding County, South Dakota: U.S. Geol. Survey Prof. Paper 476-A, p. A1–A64.
[11] F. W. Osterwald, 1965, Structural control of uranium-bearing vein deposits and districts in the conterminous United States: U.S. Geol. Survey Prof. Paper 455-G, p. G121–G146.

series summarizing characteristics of such deposits. Although no one kind of structure is particularly favorable, most deposits in veins are in places where small- to intermediate-scale faults, joints, and folds were formed adjacent to large- to intermediate-scale faults (Taft-McKittrick area, California), anticlines (Front Range, Colo.), and intrusive bodies, or between two intermediate- to large-scale faults (Cochetopa district, Colorado, and Marysvale, Utah).

Distribution of selenium in some uranium deposits

Uranium, vanadium, and selenium have a zonal distribution in and near some roll and tabular uranium-vanadium ore bodies in sandstone on the Colorado Plateau (D. R. Shawe, p. B169–B175). The zones are concentric with the curved surfaces of the roll bodies and parallel to the boundaries of tabular bodies. The zonal arrangement is particularly clear for selenium, which tends to be most concentrated in a thin shell or zone at the interior margin of uranium-vanadium ore.

A similar zonal arrangement of selenium with respect to uranium is also characteristic of roll-form bodies of uranium ore in Tertiary rocks in the Shirley basin, Wyoming, as reported by E. N. Harshman (p. C167–C173) and as found by A. P. Butler from sampling a similar deposit in the Powder River basin, Wyoming. (See also "Geochemistry of Ore Deposits.")

Some, and perhaps most, of the selenium in unweathered parts of uraninum deposits in the Powder River and Shirley basins occurs as ferroselite ($FeSe_2$), the selenium analog of marcasite, which was first identified in a Powder River basin deposit by H. C. Granger (p. C133–C137).

THORIUM

Rare earths and thorium in carbonate veins, Fremont County, Colo.

In the northern Wet Mountains, Fremont County, Colo., M. H. Staatz and N. M. Conklin (p. B130–B134) report carbonate veins containing four rare-earth-bearing minerals—monazite, bastnaesite, thorite, and fergusonite—along a northeast-trending shear zone 1,560 feet long. The shear zone is 1.4 miles west of the large alkalic intrusive complex centered around McClure Mountain. In contrast to the siliceous, thorium-bearing veins southeast of the alkalic complex, the veins west of the complex are characterized by carbonate gangue and a content of rare earths exceeding that of thorium. They probably should be classed as carbonatites.

MINOR ELEMENTS

Distribution and concentration of minor elements in black shale statistically evaluated

A study by J. D. Vine of correlation statistics from a number of sets of black-shale samples suggests that different environments of black-shale deposition provide a wide variety of characteristic minor elements. The minor elements can be grouped in each set by a positive or negative correlation with the characteristic major elements. Thus it is possible to distinguish minor elements that are characteristically associated with the detrital mineral fraction, the organic matter, or the chemically precipitated fraction of the rock. The detritial fraction is generally characterized by Ti, Zr, and Ga, but may also include B, Ba, Be, Sc, and Sr; it may even include Cr and V if the rock is not enriched in these elements. The organic-matter fraction is generally characterized by Cu, Ni, and Mo, even though these elements may be present only in very small amounts. In metal-rich rocks, the organic matter is normally characterized, in addition, by V and Cr and by one or more elements of a group that includes Ag, B, Co, Pb, Se, U, and Zn. Where carbonate minerals predominate in the chemically precipitated fraction, Sr and Mn are present; where phosphate minerals predominate, La, Y, and other rare-earth elements may be included; where silicate minerals predominate, the Ba or Ti content may be high; where sulfide minerals are abundant, Ni, Co, and Tl may be characteristic trace elements; and if saline minerals are present, B enrichment is common.

ORGANIC FUELS

U.S. Geological Survey research pertaining to organic fuels is directed toward evaluating geologic environments favorable for fuel accumulations, establishing resource estimates, and studying the geochemistry and origin of fossil fuels. Results of stratigraphic, structural, and areal geologic studies related to work on organic fuels are summarized in results of regional investigations; only findings concerning fuel resources and organic geochemistry are reported below.

COAL

Coking coal resources in Western United States

In a recent summary of coking-coal deposits in the Western United States, Paul Averitt (r0324) has described the geology and coal resources in 21 localities in 8 States. Three of the localities, the Raton Mesa region, Colorado–New Mexico, the Carbondale field, Colorado, and the Sunnyside-Castlegate field, Utah, are important sources for metallurgical coke used by the western steel industry. Other areas yield coal suitable for manufacture of lower grade coke. Some areas still are undeveloped. Most of the areas have been mapped and described by the U.S. Geological Survey.

Revised estimates of coal resources in Arkansas

Estimates of original coal resources in the Coal Hill, Hartman, and Clarksville quadrangles, Johnson County and vicinity, Arkansas, have been revised upward by E. A. Merewether and B. R. Haley on the basis of detailed geologic mapping and additional coal-thickness data. Original resources are now estimated to be 45 million short tons of low-volatile bituminous coal and 336 million short tons of semianthracite, representing increases of 180 percent and 24 percent, respectively, over previous estimates made by Haley.[12]

Coal beds of economic importance in northern New Mexico

Detailed geologic mapping by C. L. Pillmore in the Catskill NW and Casa Grande quadrangles, northern Colfax County, N.M., has delineated several coal beds of economic importance near the base and in the upper part of the Raton Formation of Late Cretaceous and Paleocene age, and in the Vermejo Formation of Late Cretaceous age. Two beds of high-quality bituminous coal near the base of the Raton Formation range in thickness from 36 to 56 inches for the lower bed and from 63 to 81 inches for the upper bed. Resources of about 18.4 million short tons are estimated for the beds under less than 1,000 feet of cover. One coal bed at the top of the formation is as much as 55 inches thick and extends over an area of 40 square miles in the Casa Grande quadrangle. Calculated resources in this bed total 78.5 million short tons.

Coal beds near the base and top of the Vermejo Formation are as much as 10 feet thick at Vermejo Park dome; the beds are lenticular over a distance of 2 to 3 miles in an east-west direction, but are more continuous in a north-south direction. Establishment of a new railhead and coal-preparation plant 4 miles east of Vermejo Park increases the commercial potential of the Vermejo coals.

New estimate of bituminous coal resources in Texas

W. J. Mapel estimates that bituminous coal resources within Texas in beds more than 14 inches thick and under less than 3,000 feet of cover total 6,100 million short tons. This figure is about 25 percent less than the estimate of 8,000 million short tons made by Campbell and Parker in 1909.[13] The new estimate includes 5,400 million short tons of coal of Pennsylvanian and Early Permian age in north-central Texas, and 665 million short tons of coal of Cretaceous or early Tertiary age in the Eagle Pass, Santo Thomas, and San Carlos districts. About 65 million tons of coal of Cretaceous age is estimated to be present in the poorly explored parts of Brewster and Presidio Counties.

PETROLEUM AND NATURAL GAS

Estimates of original world resources of petroleum and natural gas

In a recently completed study, T. A. Hendricks (r1693) estimates that the amount of crude oil originally in place in the world amounted to slightly less than 10,000 billion barrels, of which approximately 1,600 billion barrels was in the United States. Natural gas originally in place in the world is estimated at more than 30,000 trillion cubic feet, of which about 4,000 trillion cubic feet was in the United States. Liquids originally contained in the natural gas of the world are estimated at more than 800 billion barrels, of which about 120 billion barrels was in the United States.

OIL SHALE AND HUMATES

World resources of oil shale evaluatd

According to a recent study by D. C. Duncan and V. E. Swanson (r1673) organic-rich shale deposits of the world land areas, including the United States, contain approximately 900 trillion tons of organic matter which has an energy potential of about 24,000 Q (10^{18} Btu). These deposits have an alternative potential yield of more than 2 quadrillion barrels of oil. Deposits of organic-rich shale in the United States are estimated to contain an order of magnitude of 72 trillion tons of organic matter.

Yields from oil shale in northern Alaska summarized

A report by H. A. Tourtelot and I. L. Tailleur (r0125) summarizes the oil yield and semiquantitative spectrographic analyses of oil-shale samples from the central and western Brooks Range, Alaska. Yields of 3 to 144 gallons of oil per ton are reported for samples from the central Brooks Range, and maximum yields of 24 gallons per ton from the western Brooks Range. Anomalously large amounts of minor elements, including mercury, silver, and gold, occur in oil shale of the central Brooks Range. The oil

[12] B. R. Haley, 1960, Coal resources of Arkansas, 1954: U.S. Geol. Survey Bull. 1072-P, p. 795–831.

[13] M. R. Campbell and E. W. Parker, 1909, Coal fields of the United States: U.S. Geol. Survey Bull. 394, p. 7–26.

shale is present in several different stratigraphic sequences that may be of several different ages in the span of early Middle Jurassic to middle Early Cretaceous. The deposits are generally thin and have been strongly folded and faulted; but the great areal extent indicates that large amounts of the rock are, or were, present.

Oil content of Antrim Shale in Michigan basin

In a summary of the geologic history of the Michigan basin, G. V. Cohee (r0070) reports that the Antrim Shale, an organic-rich black shale of Late Devonian age, locally contains as much as 17 gallons of oil per ton of shale. The Antrim ranges in thickness from 150 feet along the eastern and northern margin of the basin to 700 feet in the central part of the basin. A resource of 20 trillion tons of organic-rich shale, containing 1 to 2 trillion tons of organic matter, is represented by the shale.

Humate deposits of northwestern Florida

Four deposits of humate, which may be of future economic significance, have been delineated by V. E. Swanson from outcrop information in the Florida panhandle. The largest deposit, in southeastern Walton County, contains an estimated 2 million tons of extractable humate. A deposit in south-central Gulf County contains on the order of 250,000 tons of humate; and two smaller deposits, one in southwestern Franklin County and the other in south-central Okaloosa County, each contain about 50,000 tons of extractable humate. Because of its metal sorptive properties, large tonnages, and thin overburden in coastal dune sands, the Florida humate may find use in the chemical and fertilizer industries (V. E. Swanson and others, p. C174–C177).

MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT

The Wilderness Act and the Conference Report on Senate Bill 4, 88th Congress, direct the U. S. Geological Survey and the U. S. Bureau of Mines to make mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe," when the act was passed, were incorporated into the National Wilderness Preservation System. Areas classed as "primitive" were not included into the Wilderness System, but the act provided that each primitive area should be studied for its suitability for incorporation into the Wilderness System. Mineral surveys constitute one aspect of such suitability studies. Field studies on the mineral resources of 9 primitive areas were completed by the Geological Survey and Bureau of Mines during fiscal year 1966, and studies on 2 other primitive areas are continuing. Several additional primitive areas are scheduled for study in the coming year.

San Rafael primitive area, California

A mineral-resource study of the San Rafael primitive area, near the coast in south-central California, has been made by H. D. Gower and others (r2016). There is no known mineral production from this primitive area nor were deposits approaching ore grade recognized here. Limestone in the southeast part of the area meets specifications for some commercial uses, but it is unfavorably located with respect to similar, more accessible deposits. The formerly productive Cachuma quicksilver district adjoins the primitive area on its southwest side, but a careful search for visual evidence of mercury in the southwest part of the San Rafael primitive did not turn up any evidence for such mineralization here. Geochemical sampling identified anomalous concentrations of mercury in Sulphur Spring Canyon, but the likelihood of near-surface mercury ore bodies is low, and the possibility of discovering such ore bodies by deep exploration is economically unattractive. Although deposits of phosphate, diatomite, and gypsum occur in nearby areas, the host rocks for these deposits are not present within the San Rafael primitive area.

Stratified primitive area, Wyoming

A small part of the Stratified primitive area, totaling about 10 square miles in northwestern Wyoming, is mineralized sporadically, according to K. B. Ketner and others (r0079). The area adjoins, and is southeast of, the Kirwin mining district. Scattered patches of altered rocks in the primitive area contain lead, zinc, copper, silver, and molybdenum in quantities several times the normal content for rocks in the rest of the primitive area. The mineralized part of the area, which has a potential for concealed deposits and is worthy of further exploration, has mining claims, some of them patented.

Coal, bentonite, and phosphate may underlie parts of the primitive area but at depths such that exploration and mining of them would be prohibitively expensive. Intrusive rocks that penetrate possible oil- and gas-bearing formations in all parts of the primitive area greatly reduce the chances of finding oil and gas here.

Mount Jefferson primitive area, Oregon

G. W. Walker and others (r0325) describe the Mount Jefferson primitive area, in west-central Oregon, as being part of an elongate volcanic plateau with several large extinct or possibly dormant volcanoes. The geologic environment is not favorable for the occurrence of valuable mineral deposits. Several localities, chiefly near extinct volcanic vents, contain alunite and native sulfur, but neither of these is present in sufficient quantity to be of commercial importance. Rock samples and panned concentrates of stream sediments lack concentrations of potentially valuable metallic minerals. Cinders usable as construction material occur in cones and in discontinuous layers; they are widely distributed within the primitive area but are not considered economically exploitable because of the abundance of more favorably located cinder deposits elsewhere in Oregon.

Flat Tops primitive area, Colorado

Much of the Flat Tops primitive area of northwestern Colorado is capped by extensive basalt flows of Tertiary age that form a broad, fairly level plateau according to W. W. Mallory and others.[13a] Within the primitive area and elsewhere in Colorado these Tertiary basalts generally are barren of mineral deposits. The Leadville Limestone, of Mississippian age, immediately underlies the basalt over a wide part of the primitive area, and elsewhere is a favorable host rock for mineral deposits. Consequently, hundreds of stream and soil samples were collected from canyons and gullies peripheral to the basalt caprock and analyzed by chemical and spectrographic methods. A few localities were found to contain metallic concentrations somewhat higher than the low values common for the area, but no significant evidence of ore deposits was discovered. The presence of commercial quantities of oil and gas within the area is highly improbable, as are the prospects for coal.

Spanish Peaks primitive area, Montana

Reconnaissance geologic mapping and semiquantitative spectrographic and chemical analyses of nearly 300 stream-sediment and bedrock samples did not indicate that any potentially economic mineral deposits are present within the Spanish Peaks primitive area, in southwestern Montana according to G. E. Becraft and others (r0392). Asbestos (anthophyllite) occurs in a few places in the eastern part of the primitive area. The largest prospect is on Table Mountain, but the veins are too small and the material is too low in grade to be of economic interest. Metamorphosed Precambrian host rocks of the Table Mountain asbestos deposit also contain chromite, averaging about 11 percent Cr_2O_3, but this grade is too low and the deposit is too small to be mined. Large altered zones were found along the Spanish Peaks fault and the Deer Creek shear zone, but neither visual examination nor analyses of samples indicates the presence of any mineral deposits. There has been no mineral production from the Spanish Peaks primitive area.

[13a] W. W. Mallory, E. V. Post, P. J. Ruane, and W. L. Lembeck, 1966, Mineral resources of the Flat Tops primitive area, Colorado: U.S. Geol. Survey Bull. 1230–C, p. C1–C30.

MINERAL RESOURCES OF APPALACHIA

As part of the overall effort to stimulate the lagging economy of Appalachia, available information on the mineral resources of the region is being summarized in a current study. This work shows that the production of mineral resources could be considerably expanded, for use both within and outside of Appalachia. One of the best hopes for accelerating the regional economy lies in greater local utilization of the very large fuel resources of the region. The coal as well as oil and gas resources of the region have fueled the industrial growth of the eastern United States. Coal resources are available in about 40 percent of the area, and to date have provided about $28 billion worth of production. More than 300 billion tons of bituminous coal resources are now known in the region, the minable portion of which is sufficient to support 440 years of production at the 1964 mining rate (about 350 million tons per year). Up to now, exploration for oil and gas has probed only the shallower stratigraphic zones. Recent discoveries in eastern Ohio and eastern Kentucky suggest that more intensive exploration at greater depths may add to the known large oil and gas resources of the region.

In addition, Appalachia's abundant resources of salt, glass sand, and other high-purity silica products, clays, high-purity limestone, dolomite, and feldspar, are the raw materials of a growing number of products vital to industry. Building-material resources also are abundant and are being used extensively; they represent another segment of Appalachia's raw-materials base that has a capacity for further development. Particularly, the cement, crushed stone, and lightweight-aggregate raw materials are of major significance in contributing to the further economic growth of the region.

Reserves of zinc, discovered in eastern Tennessee during recent years, have been developed to the point where Tennessee leads all other States in production of this metal, a position Tennessee is expected to maintain for an indefinite period. The possibilities of discovering new zinc deposits in Appalachia are considered excellent.

TECHNIQUES OF MINERAL EXPLORATION

Pathfinder elements in geochemical prospecting

The study of primary dispersion patterns in bedrock related to hypogene mineralization has been the subject of intensive study. Recent work indicates that some of the volatile elements, such as tellurium and mercury, are useful pathfinders in prospecting for concealed deposits of base and precious metals. The greater mobility of these volatile constituents apparently permits the formation of a primary leakage halo above deposits containing less mobile metals such as gold, copper, and lead. The recent development of very sensitive analytical methods for the determination of tellurium, mercury, silver, and gold has now made it possible to study the geochemical distribution and abundance of these pathfinder elements.

In the Ruth porphyry copper deposit in Nevada, geochemical investigations by G. B. Gott and J. H. McCarthy, Jr., have revealed a strong metal zoning that may lead to the discovery of additional concealed porphyry copper deposits. The central part of the district, wherein copper, iron, bismuth, and molybdenum are concentrated, is surrounded by a broad peripheral zone in which zinc, lead, antimony, mercury, silver, and tellurium are concentrated. Because of the enormous enrichment of tellurium compared to its crustal abundance—5- to 10-million-fold enrichment in this district—it is probable that tellurium is one of the best indicator elements that can be used for prospecting in the Egan Range.

Gott and McCarthy also report that the gold telluride deposits in the Cripple Creek district in Teller County, Colo., have small quantities of mercury that correlate closely with the distribution of the gold in the exposed rocks. Although tellurium is also spatially closely associated with the gold, its distribution in the oxidized surface rocks is much more extensive than is the distribution of either gold or mercury. Anomalous amounts of tellurium and silver occur in the entire district, but anomalous amounts of gold and mercury are largely restricted to the areas where gold has been mined.

Another example of hypogene zoning related to an intrusive center is reported by W. J. Moore and others (p. C197–C205), who made a study of metal distribution in bedrock and oxidized surficial material in the Stockton district in northeastern Utah. Largely coextensive areas of locally high bismuth-copper-molybdenum content define a central zone; lead-zinc areas of greater lateral extent partially overlap the central zone; and locally high arsenic-antimony (and boron?) content characterizes the outer zone, with boron extending beyond the limits of significant known mineralization. Silver is erratically distributed in the area studied. (See also the section "Utah" under "Regional Geology.")

T. G. Lovering, H. W. Lakin, and J. H. McCarthy, Jr. (p. B138–B141), have studied the mercury and tellurium content of 93 jasperoid samples from 22 areas, including 14 mining districts. The samples were classified on the basis of their field relations, composition, and other characteristics as either "favorable type" (commonly associated with ore), or "unfavorable type" (not commonly associated with ore). The tellurium content of these samples ranged from 200 parts per million to <0.1 ppm, and the mercury content ranged from 90 ppm to 0.02 ppm. They found tellurium content of more than 1 ppm and mercury content of more than 5 ppm to be characteristic of jasperoid of the favorable type.

Present techniques, such as spectrographic analysis and vapor absorption, for determining the small amounts of mercury in hypogene zoning patterns require elaborate and expensive instrumentation, and this has tended to reduce the potential usefulness of mercury surveys in geochemical prospecting. Accordingly, a simple chemical colorimetric procedure has been devised by Margaret Hinkle, Kam Wo Leong, and F. N. Ward (p. B135–B137) to offset the limitations imposed by the costly instrumentation. The method is based on the catalytic effect of mercury on the reaction of ferrocyanide with nitrosobenzene to produce a violet-colored compound. The mercury is released by heating a sample of soil or crushed rock to about 650°C. As little as 30 nanograms (3×10^{-8}) of mercury can be detected. The reliability of the method is adequate to permit its use in geochemical surveys that utilize mercury as a pathfinder element.

Use of bryophytes in geochemical studies

Studies of the element content of bryophytes (mosses and liverworts) by H. T. Shacklette (r1607) that were growing on various substrates in Wisconsin, Missouri, and Kentucky revealed that these plants absorb a greater number of elements than do the flowering plants from the same regions. Bryophytes were found to concentrate 27 elements to higher levels in their tissues than those levels found in the substrates on which they grew. Of 43 elements that occur in the tissues of bryophytes, only beryllium, lanthanum, titanium, and zircon were found in greater quantities in the substrates than in the ash derived from bryophytes that grew on these substrates. Very high percentages of barium (5.0), copper (0.2), lead (2.0), strontium (0.15) and zinc (2.0) were found in the ash of certain samples. Of all groups of the plant kingdom, only bryophytes contained niobium and scandium. On the other hand, cadmium, lithium, and rhenium were found in flowering plants but not in bryophytes. Bryophytes may be useful in regional geochemical evaluations because of their pronounced ability to concentrate the rare-earth elements that may not be detected in other sampling media.

Stream-sediment and soil-sampling results

In the field of reconnaissance for mineral deposits based on the sampling and analysis of stream sediments, cobalt is reported by F. C. Canney and L. A. Wing (r2008) to be a very useful element, especially as a pathfinder for nickel-copper-cobalt deposits associated with mafic rocks. Their data strongly indicate that cobalt is normally a highly mobile element in the supergene environment, certainly more so than copper and nickel, and they suggest that this high mobility is a property that should be exploited more fully in reconnaissance prospecting surveys based on stream-water or stream-sediment analysis.

High concentrations of copper, lead, and zinc were found locally in soils in Marquette County, Mich. by Kenneth Segerstrom and W. H. Raymond (p. D186–D189). Most of these base-metal concentrations are locally derived, and their migration and local concentrations are largely postglacial.

Data of interest to those concerned with geochemical prospecting for concealed ore deposits in glaciated areas are contained in a report by F. C. Canney (r1487), who made geochemical prospecting studies in the copper belt of Orange County, Vt. Canney found that anomalous patterns of copper are present in the soils over and adjacent to suboutcropping pyrrhotitic copper deposits concealed by a thin mantle of basal till and that the total copper content of B-Zone soil samples can be used as a guide in the search for anomalous areas.

Precise borehole gravimeter developed

A precise borehole gravimeter that shows great promise as a tool for petroleum exploration and development and for geologic research, has been tested successfully. The instrument was designed at the suggestion of T. H. McCulloh (r0748), of the U.S. Geological Survey, and developed as a result of close cooperation between Geological Survey geologists and representatives of the industrial firm of LaCoste and Romberg, Inc. The gravimeter, a specially constructed modification of the patented LaCoste and Romberg geodetic gravity meter, was designed to measure gravity in wells cased with 7-inch or larger casing and at temperatures below 100°C. Initial tests to depths of 4,150 feet in a well at Santa Fe Springs oil field, California, indicated that the precision of the instrument is ±0.015 milligal; the precision may be improved to ±0.005 mgal with some instrument refinement and further operational experience. The tests suggest that the borehole gravimeter is of potential commercial value for measuring rock density and porosity in situ underground, for constructing subsurface gravity maps to be used in exploration for undiscovered petroleum reservoirs in already explored areas, and for investigations of known reservoirs that are incompletely developed.

OFFICE OF MINERALS EXPLORATION

The functions of the Office of Minerals Exploration (OME) were transferred to the U.S. Geological Survey in July 1965. The OME, like its predecessor agency, the Defense Minerals Exploration Administration (DMEA), has as its prime objective the stimulation of mineral exploration and the expansion of the mineral resource base of the United States.

Under the OME program financial assistance is extended to mine operators for exploration of certain eligible minerals and mineral products. Applicants for financial assistance are requested to describe fully the proposed exploration; they must include evidence that funds for the exploration work are unavailable on reasonable terms from commercial sources, and they must certify that they would not normally undertake the exploration at their sole expense under current conditions or circumstances. All applications are evaluated by OME on the basis of the following criteria:

(1) Geologic probability of a significant discovery being made.

(2) Estimated cost of the exploration in relation to the size and grade of the potential deposit.

(3) Plan and method of conducting the exploration.

(4) Accessibility of the project area.

(5) Background and operating experience of the applicant.

(6) Applicant's title or right to possession of the property.

If an application is approved, the Government may enter into an exploration contract with the applicant, under terms and conditions set forth in a contract form. The Government will contribute not more than 50 percent of the total allowable costs of the exploration specified in the contract, for all minerals except silver, for which the Government will contribute up to 75 percent of allowable costs. The Government's share of exploration costs is paid monthly, only after the work for which the costs accrued has been completed. If the work results in a discovery the Government is repaid with interest at the rate of 5 percent royalty on production from the property. If there is no production, no repayment is required.

Under the Geological Survey, the OME administrative office is headquartered in Washington, D.C. Four Survey field offices are maintained, one at S. 157 Howard Street, Spokane, Washington, which services the states of Idaho, Montana, Oregon, and Washington. A second field office is at 345 Middlefield Road, Menlo Park, California, for Alaska, California, Hawaii, and Nevada. A third office is at the Denver Federal Center, Denver, Colorado, for Arizona, Colorado, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, and Wyoming. All other states are served through the Survey office in the Post Office Building, Knoxville, Tennessee. Application forms and information pertaining to the program may be obtained at these offices.

During the period July 1, 1965 to June 1, 1966, 87 applications for exploration assistance were received by OME, 73 of which were primarily for silver, and the rest for other eligible metals. A total of 13 exploration contracts were awarded, the Government's approved participation in which amounted to $504,495. Ore was discovered in 3 exploration projects, bringing to 18 the number of projects that have been certified as discoveries since the OME program began in 1959. At current market prices, the ore discovered in these 18 projects is estimated to have a recoverable value in excess of $18,000,000.

WATER RESOURCES

The U.S. Geological Survey investigates the occurrence, availability, and quality of surface and underground waters and the sediment discharge of streams. A hydrologic-data network which extends throughout the country provides continuing series of several types of basic data. During 1966, discharge and water-level data for surface waters were collected at about 8,300 stream-gaging stations and about 1,130 lake- and reservoir-level stations. Continuous or periodic measurements of ground-water levels were made in about 16,000 observation wells. The quality of surface waters was monitored at about 1,960 stations; chemical, temperature, and sediment data were collected.

Included among these observation stations are about 40 hydrologic bench marks which had been established by the end of the fiscal year. Each of these is a small basin, as yet unaffected or little affected by man's activities, in which long-term hydrologic observations will be made. At present, one stream gage has been established in each basin, and water samples are being collected for analysis. These observations will provide a basis for understanding hydrologic changes which may occur in nearby basins as a result of man's influence, and will document natural long-term hydrologic changes.

The Geological Survey is taking part in the International Hydrological Decade, a 10-year effort of cooperative international studies in scientific hydrology. A principal goal of the Decade is the determination of a global balance of water and waterborne materials. As part of its activity in the Decade program the Geological Survey is observing a 49-station hydrologic network; the stream-discharge, chemical-quality, and sediment data obtained will provide a general index of the discharge of water and of dissolved and suspended material from the continent to the seas. Data from the hydrologic bench marks will show natural hydrologic conditions. Measurements of the tritium content in water in the 20 principal rivers in the United States, and in precipitation at 16 localities, will be used to evaluate the role of precipitation in determining the chemical characteristics of inland waters. As its part in glaciological studies, which will also play an important role in the determination of the global water balance, the Survey is monitoring representative glaciers in Alaska and the Western States. These glaciers are part of an observational chain which extends along the Pacific Ocean from the Arctic to the Antarctic regions. Geomorphological studies are also being made as a means of monitoring hydrologic processes (see discussion of the Vigil Network, in the section "Geomorphology").

Basic hydrologic data collected by the Geological Survey are published in the following Water-Supply Paper series of the Geological Survey:

"Surface Water Supply of the United States,"
"Ground-Water Levels in the United States,"
"Quality of Surface Waters of the United States," and
"Quality of Surface Waters for Irrigation, Western United States."

The Surface Water Supply series, formerly published annually, is to be published at 5-year intervals beginning with the period 1961–65. Each report is in 16 parts: 14, determined by drainage basins, for the 48 conterminous States, and one each for Alaska and Hawaii. Interim annual reports by States are being published. The reports on water quality are published annually, but conversion to summary publication with an initial 1964–65 volume, and subsequent 5-year volumes beginning with the period 1966–70, is anticipated. Interim annual reports, by States, will also be published. The water-quality records are grouped in terms of the same drainage basins used for the reports on surface-water supply. The reports on ground-water levels, in 6 parts which represent geographical sections of the country, also represent 5-year periods, although the periods are staggered so that one ends in each of four successive years and two end in the fifth year. In addition to all these basic-data reports, a series of Water-Supply Papers is published which describes the magnitude and frequency of floods for the entire country, by drainage-basin areas, and another series describes notable floods each year.

Areal investigations of water resources are made largely in cooperation with State, local, or Federal agencies listed on page A211. These studies include the various aspects of the geologic and hydrologic environment that relate to the occurrence and movement of water on the surface and underground. Such studies of water resources stress the evaluation of sources of supply, chemical and physical composition, computation of the quantity available for use, description of the direction and rate of movement, evaluation of fluctuations in flow, and determination of disposition of the supply as use, waste, or outflow.

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

Investigations stressing the economic aspects of water as a resource are treated in the following section under four areas (fig. 1), which correspond to the administrative subdivisions of the Water Resources Division.

FIGURE 1.—Index map of the United States, showing areal subdivisions used in discussion of water resources.

ATLANTIC COAST AREA

The Atlantic coast area, which includes the coastal States, the remainder of New England, Pennsylvania, West Virginia, Puerto Rico, and the Virgin Islands, is characterized by a wide range in climatic conditions, hydrology, and cultural patterns. Generally speaking, water supplies in the area are moderate to plentiful, and in most years sufficient water has been available for most needs. However, several factors, notably pollution and the areal intensity of use for municipal, industrial, and agricultural purposes, have affected the adequacy of an increasing number of supplies. During 1966 the continuation of drought in the Northeastern States was also a significant factor in water supply. Investigations of water resources in the Atlantic coast area by the U.S. Geological Survey have as their objective the description of the occurrence of water, with emphasis on problems which affect water use. The results of typical investigations of the occurrence, quantity, and quality of underground and stream waters are summarized in the following pages. Among new studies recently begun are the investigation of Atlantic coast estuaries, in cooperation with the States, and a study of ground-water resources of the Appalachian region, in cooperation with the U.S. Army Corps of Engineers.

INTERSTATE STUDIES

Effects of drought in the Northeast on water supply

H. C. Barksdale, Deric O'Bryan, and W. J. Schneider have made a preliminary appraisal of the effects of the drought in the Northeastern States as of March 31, 1966. A report describing the effects of the drought on water resources was in preparation at the end of the 1966 fiscal year, for publication early in fiscal year 1967.

Drought may be said to occur during a period of less-than-average precipitation, if it is long enough and severe enough to affect man's activities. The Northeast drought is the longest and most severe in the recorded history of the region, and more than 100 public water supplies were critically short of water in 1965 or were seriously threatened with critical water-supply problems. However, studies by the Geological Survey, made in response to the President's declaration of a limited national emergency in parts of the drought-stricken area, showed that suitable emergency water supplies are available to all these communities. The appraisal indicates that there has not been an overall shortage of water for public supply in the Northeastern States. Careful planning and construction of facilities for the collection, storage, treatment, and delivery of water, together with pollution abatement and reasonable measures of water conservation, should make the water supplies of the Northeast practically droughtproof for many years to come.

(See also discussion of drought conditions in the section "New Jersey," below.)

Ground-water map of Connecticut River basin

D. J. Cederstrom and A. L. Hodges, Jr., working in cooperation with the U.S. Army Corps of Engineers, have prepared a map of the Connecticut River basin in Massachusetts and Connecticut which shows the favorability of the alluvial and glaciofluvial deposits for the development of ground-water supplies. Three general areas are distinguished: the eastern highlands, the western highlands, and the intervening Triassic lowland.

Conditions are most favorable for large ground-water supplies in the eastern highlands, where 1 to 5 million gallons per day can be obtained by well fields in some valleys. For example, one well at Athol, in north-central Massachusetts, yields 1,560 gallons per minute, and one at South Barre, Mass., 1,080 gpm. In the western highlands, gravel is less common and the deposits are much less favorable for the recovery of large ground-water supplies. The lowland is divided into eastern and western parts by basalt ridges. Deep preglacial channels are known west of the basalt ridges in both Connecticut and Massachusetts; in the vicinity of Deerfield, Mass., the bedrock is at least 235 feet below sea level. Large ground-water supplies are obtained locally by municipal wells which tap sand and gravel in the deep channels west of the basalt ridges. For example, two wells at Westfield, Mass., each yield 2 mgd. The lowland east of the ridges is generally a poor area for the development of large supplies because it is underlain largely by fine-grained lake sediments. In a few places, however, deltaic gravel may underlie the lake beds. One buried delta is present near Agawam, south of West Springfield, Mass., and another may be present southeast of the gap in the basalt ridge near Northampton, Mass.

Potomac-Raritan-Magothy aquifer system

H. E. Gill and Donald Langmuir are studying the Potomac-Raritan-Magothy aquifer system in the Atlantic Coastal Plain between Sandy Hook, N.J., and New Castle, Del., to determine the geologic framework of the aquifer system (see under "Atlantic Coastal Plain" in the section "Regional Geology"), and the nature and extent of hydrologic and geochemical controls on ground-water chemistry.

Prepumpage piezometric maps constructed from water-level measurements made around 1900 indicate two major flow systems in the Potomac-Raritan-Magothy aquifer system. The first flow system is characterized by a major recharge area where the formation crops out at greatest elevations in Mercer and Middlesex Counties, in north-central New Jersey. This flow system discharges into Raritan Bay to the north and into the Delaware River, near Trenton, to the south. The second flow system is recharged along the Delaware River in the outcrop areas of the Potomac and Magothy Formations from south of Trenton to Salem County in southern New Jersey. Geochemical measurements in this area indicate that the ancestral Delaware River was probably the source of recharge, during the Pleistocene, for the water presently being withdrawn from the Potomac-Magothy aquifer system.

The Potomac-Magothy aquifer system displays pronounced directional permeability parallel to the long axes of buried southeast-trending stream channels south of Trenton. Detailed measurements of pH, temperature, and concentrations of such chemical species as bicarbonate, ferrous iron, calcium, and magnesium have shown pronounced migration of ground water up the channels to the northwest since pumpage began around 1910.

Calculations based on the chemical analyses indicate that the solubilities of limonite and siderite exert a strong control on concentrations of dissolved ferrous iron in the ground water. These conclusions are supported by laboratory solubility measurements on siderite oolites which have been separated from cores from the Raritan Formation.

Ground-water resources of the Susquehanna River basin

Studies by P. R. Seaber and E. F. Hollyday, made in cooperation with the U.S. Army Corps of Engineers, indicate that in the Susquehanna River basin in New York State, wells in Pleistocene sand and gravel are potentially 40 times more productive than wells in Devonian bedrock. Fine-grained lacustrine deposits are predominant in the Pleistocene section in much of the upper reaches of the Susquehanna River valley and valleys of its tributaries above Binghamton, and in the Canisteo River valley. However, 10 to 40 feet of highly productive water-bearing sand and gravel is located in the following areas: The entire Cohocton River valley between Cohocton and Corning, at least four-fifths of the Chemung River valley between Corning and Waverly, at least four-fifths of the Susquehanna River valley between Kirkwood and Waverly, at least two-thirds of the reaches of the Chenango and Tioughnioga River valleys, and at least half of the valley reaches of the Susquehanna River basin above Susquehanna, in northeastern Pennsylvania.

NEW ENGLAND

Ground-water conditions in the central Boston area

Subsurface hydrology is of special concern in planning the route of the proposed Inner Belt Highway, the construction of which will involve considerable excavation in the central Boston area, because decline of ground-water levels during highway construction might lead to rotting of the wooden foundation pilings present beneath most of the older buildings. The complexity of subsurface conditions is shown by a study in progress by J. E. Cotton, which concerns such problems as old and new foundations and retaining walls; watertight subways; leaky sewers (some recharging and some draining); and a local base level (the Charles River Dam), outside which the ground-water level fluctuates with the tide. An overall generalization of the ground-water hydrology of Boston seems impracticable, and further study will be limited to the immediate vicinity of the highway.

Water resources of the Millers River basin, Massachusetts

A study being made in the Millers River basin, in north-central Massachusetts, by R. M. Collins and D. R. Wiesnet shows that glaciofluvial deposits in the Orange and Athol areas, the valleys of Trout Brook, North Pond Brook, and Otter River, and in the Lake Denison area are good prospects for developing wells capable of producing 0.1 million gallons per day. Yields as high as 2 mgd may be possible in a few places. The ground water is generally of good quality but locally may contain excessive amounts of iron.

Very little use is made of surface water for water supply. The main stem of the Millers River is highly polluted for about three-quarters of its length. However, water in most of its tributaries is of good quality.

Ground water in the Potowomut-Wickford area, Rhode Island

The transmissibility of the sand and gravel aquifer underlying the Potowomut-Wickford area ranges from less than 10,000 to more than 300,000 gallons per day per foot. J. S. Rosenshein, J. B. Gonthier, and W. B. Allen have found that three small drainage basins contain four areas in which the aquifers are of sufficient permeability and saturated thickness to sustain a total withdrawal of 18 million gallons per day during exceptional dry years such as 1963. Part of this withdrawal would be obtained from stream infiltration, and as a result of it some streams might have no flow for as long as 160 days during exceptionally dry years.

NEW YORK

Hydrology of Flint Creek basin

Studies by D. E. Vaupel in the upper Flint Creek basin, in Steuben and Yates Counties in western New York, show that in an average year over two-thirds of the precipitation, or approximately 1,250 acre-feet per square mile, is returned to the atmosphere by evapotranspiration. During periods of high evapotranspiration more than three-fourths of the ground-water discharge to upper Flint Creek is supplied by a terminal-moraine deposit located at the headwaters of the creek, even though this deposit contains only one-tenth of the drainage area of the basin.

Water resources of the western Oswego River basin

More than half the surface drainage of the area, including the discharge from Seneca and Cayuga Lakes, passes through Lock No. 1, or Mud Lock, on the Cayuga-Seneca Canal east of Seneca Falls. W. J. Shampine, L. J. Crain, and J. B. Hood, Jr., report that the rating equation which has been used to compute discharges for the important control structures at Mud Lock required reevaluation to assure that accurate flow data are available for assessing the causes and effects of changes in the levels of Cayuga and Seneca Lakes. Discharges computed from the old equation may differ from measured values by as much as 25 to 30 percent. A new equation based upon discharge measurements has been devised, and 45 years of available records have been recomputed. The new equation accounts for previously unreported leakage through the lock and gate structures.

Study of the chemical quality of precipitation indicates that there is no significant widespread mineral contamination of the air in this area. The average specific conductance of the water is 45 micromhos.

Geohydrology of Queens County

Studies by Julian Soren indicate that reduction in natural recharge to the aquifers of Queens County, resulting from rapid urbanization since about 1920, together with continued pumping, has been accompanied by the development of a deep still-growing cone of depression in the water table, and by greatly reduced storage in the ground-water reservoir. Ground water has been pumped at about the rate of 60 million gallons per day, but conspicuous spread of the area of drawdown apparently did not begin until the 1920's. Sea water is slowly being drawn into the cone of depression in the central part of the county, causing increases in hardness and chloride in the ground water. However, the overall quality of ground water, as of 1961, was still suitable for public supply and industrial use.

NEW JERSEY

Drought severity in New Jersey

The 1965 water year was the fourth consecutive year of below-average flow in all gaged rivers in northern New Jersey, and the fifth year in some of them. The drought extends generally from New England to Virginia east of the Appalachian Mountains, but preliminary appraisal by J. E. McCall indicates that the greatest severity has been in northern New Jersey and southeastern New York. The drought intensified in 1965, and new record lows for monthly and annual streamflow and ground-water levels were observed at many locations in northern New Jersey. For example, the 1965 runoff in the Pequest River basin was 5.76 inches, about one-third of the long-term average and nearly 4 inches less than the previous yearly minimum in 1932. The runoff for the 4-year period of drought was only 55 percent of the long-term average in the Pequest basin.

Salt-water encroachment in Salem County

Salt-water encroachment has occurred in the principal aquifer in the vicinity of Salem, in the Atlantic Coastal Plain in southwestern New Jersey, adjacent to the lower Delaware River and its tidal tributaries. According to J. G. Rooney, the aquifer affected is in the Mount Laurel and Wenonah Formations of Cretaceous age, and the encroachment is in deposits 50 to 180 feet below the land surface. The aquifer is an important source of water for the public-supply system of the city of Salem, serving an estimated population of about 9,700, and is also the source of supply for several large industrial plants, the Salem County hospital, and many private homes not served by the city system. Chemical analyses of water samples collected semiannually from one Salem public-supply well show that chloride concentrations have increased from 16 parts per million in 1962 to 291 ppm in November 1964. Continuous pumping of this well during the spring, summer, and fall of 1965 yielded water having an average chloride concentration of about 110 ppm. Chloride concentrations in samples collected during 1965 from other wells tapping this aquifer in the area ranged from 4.0 to 430 ppm.

Sediment yield, Passaic River basin

The annual average sediment yield has been estimated by W. G. Shope, Jr., for three locations in the

Passaic River basin in northeastern New Jersey. The largest yield is in the Passaic River at Little Falls, the most downstream station sampled, where the discharge is 171 tons of sediment per square mile. The Ramapo River near Mahwah carries 55 tons per square mile; and the Passaic near Chatham, 149 tons per square mile.

Evapotranspiration in the New Jersey Pine Barrens

E. C. Rhodehamel reports that the average yearly transpiration of water by the native oak-pine forest in the New Jersey Pine Barrens is a little less than 16 inches. Inasmuch as the total evapotranspiration averages 22.5 inches, average annual interception and evaporation losses are about 6.5 inches.

PENNSYLVANIA

Hydrology of valley fill

J. R. Hollowell has found shallow sand and gravel deposits capable of yielding 100 gallons per minute or more along the Susquehanna River in Luzerne County, in eastern Pennsylvania. The deposits are in a part of the valley deepened by Pleistocene glaciers to depths as great as 300 feet. The valley fill consists of early ice-contact deposits, overlain by lacustrine sediment which is overlain in turn by coarse fluvial deposits. The coarse materials comprise the best aquifer, and wells tapping them yield up to 400 gallons per minute. Thick deltaic deposits, originating from tributary streams, locally cross the valley and replace the lacustrine deposits. Ground-water supplies may not be found everywhere along the valley, however, because coal mines beneath it have drained the deposits in many places.

Ground water in Paleozoic sedimentary rocks

H. E. Johnson and S. F. Talian have studied data from about 60 drilled wells in the 450-square-mile area of the Valley and Ridge physiographic province in the Mifflintown and Loysville quadrangles, in south-central Pennsylvania. The major water-yielding rock units are the Tonoloway Limestone and the calcareous Wills Creek Shale, both of which are of Silurian age and consistently produce hard water. The median hardness of water from the Wills Creek Shale is about 175 parts per million and that from the Tonoloway Limestone is greater than 220 ppm. Several wells drilled in shale and sandstone units yield water that is high in iron and manganese content. The highest concentrations are in water from sandstone in the Devonian Marcellus Shale.

Cussewago Sandstone productive aquifer in Mercer County

G. E. Kimmel has found, in studying the geology and hydrology of Mercer County, that the most consistently productive aquifer in the northwestern part of the county is the Cussewago Sandstone of Mississippian age. It is about 60 feet thick and yields as much as 75 gallons per minute. In most of the area it is overlain by the Bedford Shale, which is about 20 feet thick, and by younger shales and sandstones of Mississippian and Pennsylvanian ages. In some valleys the Cussewago is directly overlain by unconsolidated Pleistocene deposits consisting of till, sand, gravel, and clay.

Water from the Cussewago is soft, and water from the overlying rocks is generally hard to very hard. However, field conductivity readings indicate that the water in the Cussewago is more highly mineralized than the water in the overlying rocks. With the exception of local areas of brackish water, conductivity of water from the Cussewago ranges from 400 to about 900 micromhos. Conductivity of water from wells in the overlying rocks generally ranges from about 200 to 400 micromhos. An analysis of water from the Cussewago indicates that it is of the sodium bicarbonate type. The water in the overlying rocks is of the calcium bicarbonate type.

MARYLAND

Flow in the Patuxent River estuary

Deric O'Bryan and J. W. Crooks report that measurements and computations of flow in the Patuxent River estuary for one tidal cycle, made during the early part of the wane of a lunar cycle, showed that about 5.4 billion gallons of water flooded upstream past the Benedict Bridge and returned seaward on the ebbing tide. The fresh-water runoff during the period of measurement, about 67 million gallons, was only a small fraction of the water that moved seaward past Benedict.

Large potential ground-water supplies on Eastern Shore peninsula

According to F. K. Mack, R. A. Gardner, and W. E. Webb, the drilling of 3 deep test holes (maximum depth 1,500 feet) has revealed the existence of 2 hitherto unexplored aquifers, in the depth range of 1,300 to 1,500 feet, in the Cambridge-Easton area on the Eastern Shore peninsula of Maryland. These ground-water reservoirs, in strata of Cretaceous age, may be an important source of water for future requirements in the developing area. Several shallower wells, drilled to depths of about 100 to 150 feet in northeastern Dorchester County, showed that Pleistocene deposits there are as thick as 120 feet. These deposits constitute a relatively extensive aquifer, and potentially, a highly productive one. On the basis of specific-capacity tests it is concluded that individual wells could be constructed which would yield water supplies of the order of several million gallons per day.

Water in the Salisbury area

Appraisal of the water resources of about 90 square miles of the Salisbury area by D. H. Boggess, R. A. Gardner, and S. G. Heidel shows that the perennial yield from the principal aquifer, the deposits of Pleistocene age, may average about 45 million gallons per day. Withdrawals of water for all uses in the area have recently averaged less than 9 mgd. Several tests conducted to define the relationship between the aquifer and Beaverdam Creek at the Salisbury municipal well field demonstrated that the aquifer receives less recharge from the stream than was previously thought. The advantage of near-stream development of wells, derived from conditions favorable for induced recharge, is now thought to have been overemphasized.

Chemical quality of Maryland surface water

A statewide chemical-quality reconnaissance of surface water by J. D. Thomas has shown the water to be satisfactory for most uses. The water in a large proportion of streams is of the calcium bicarbonate type. Streams on the Eastern Shore above tidewater, contain less than 100 parts per million of total dissolved solids. Piedmont streams generally contain higher dissolved-solids concentrations than do the Eastern Shore streams. The North Branch Potomac River, in westernmost Maryland, is polluted by mine drainage from both active and abandoned mines from its headwaters down to Savage River, where mildly alkaline water of good chemical character helps to neutralize the acidic water of the main stem. Below Luke, in Allegany County, the North Branch receives alkaline mill waste and the water commonly has a pH of 8.0. From Point of Rocks to the head of tidewater at Washington, D.C., water in the Potomac River, which provides the public supply for Washington and much of its surrounding urban area, is mostly of the calcium bicarbonate type.

WEST VIRGINIA

Use of water in the Monongahela River basin

A recent study by B. M. Wilmoth, E. A. Friel, and J. W. Wark reveals that the total quantity of water used in the Monongahela River basin in West Virginia is about 554 million gallons per day, which is about 11 percent of the 4,800 mgd that flows from the basin into Pennsylvania. Of the amount used, almost 90 percent (492 mgd) is for cooling and hydropower, and most of it is therefore available for reuse. The water available is sufficient to meet most of the requirements for the present and for many years to come.

GEORGIA

Logging reveals structural feature of aquifer

Gamma-ray logging confirms the presence of a troughlike depression in the top of the principal artesian aquifer in the area of the estuary between Jekyll Island and the Brunswick Peninsula, in southeastern Georgia. According to D. O. Gregg, preliminary evidence shows that the trough may have been forming almost continuously from late Eocene through Miocene times. This depression may be related to a hydraulic discontinuity previously found between the Brunswick Peninsula and Jekyll Island.

Salt-water encroachment in Brunswick area

The bottom parts of several high-capacity industrial wells in Brunswick were plugged because the wells penetrated a confining unit and obtained salty water from the underlying limestones. D. O. Gregg reports that the plugging reduced the chloride content from about 800 parts per million to about 35 ppm, but that it also reduced the specific capacity by 9 to 78 percent. The chloride content of water from unplugged wells nearby has increased, indicating that the salty water moves into the lower water-bearing zone of the principal artesian aquifer, through other openings, at an accelerated rate. As a result of the plugging, withdrawal from the upper zone has been increased, and drawdown is greater in the upper zone than in the lower zone. Measurements in nearby observation wells show that the water level in the upper zone declined more than 7 feet between December 1964 and December 1965, while in the lower zone it declined less than 2 feet. At a distance from these wells, water-level declines in the upper zone amount to only half a foot on the west side of the county and to about a foot on Jekyll Island for this same period.

FLORIDA

Water in Everglades National Park

C. A. Appel and Howard Klein have analyzed data from test drilling and pumping along the northern boundary of the Everglades National Park in southern Florida, and find that the transmissibility of the Biscayne aquifer there is less than 50,000 gallons per day per foot as compared with 1 to 2 million gpd/ft farther east toward Miami. It may therefore not be feasible to establish an infiltration gallery and pumping station along the northern Park boundary, as has been proposed, to furnish water at a rate of 100 cubic feet per second in an attempt to sustain ecology in the Park during droughts. The proposed pumping station may be feasible along the eastern Park boundary, 13 miles to the south, where shallow limestones are thicker and more permeable. It was determined there that a gallery at least 20,000 feet long would be required to yield the specified 100 cfs.

F. W. Meyer and M. C. Kolipinski are investigating the feasibility of using water from the Floridan artesian aquifer during periods of drought in Everglades National Park. An artesian well has been drilled near Taylor Slough, in the park, to supply mineralized water from the Floridan aquifer to an experimental plot where the effects of fresh-water biota are being examined. The chloride content of water from the test well ranges from 2,500 to 3,000 parts per million. If no material changes in the ecology are noted, consideration can be given to the use of the artesian water in drought-stricken areas of the Park.

A study by J. H. Hartwell of historical overland flows across the north boundary into the Everglades National Park showed that the period October 1952 to September 1962 was one of near-average rainfall. Monthly mean flows varied from no flow to 4,200 cfs. Median monthly flows, which varied from 21 cfs in May to 1,020 cfs in October, reflect the average, seasonal fluctuation. The average yearly flow was found to be about 250,000 acre-feet.

Potential use of saline artesian water for desalination

F. W. Meyer and Howard Klein are evaluating the potential of saline artesian water as a possible source of water supply in the Florida Keys. A deep exploratory well was recently completed at Pennekamp State Park on Key Largo, about 10 miles from the Florida mainland, to explore the quality and availability of brackish artesian water for desalination. The exploratory well, 1,333 feet deep, was completed in the Eocene Avon Park Limestone, a highly permeable unit of the artesian Floridan aquifer. The well flowed at a rate of 580 gallons per minute, and the shut-in pressure head (static water level) was 38 feet above mean sea level or 35 feet above the land surface. The chloride content of the water has ranged from 2,300 to 2,400 parts per million during a 9-month period.

A plant for desalting sea water has been authorized at Key West. The water from the Floridan aquifer is considerably less salty than sea water (2,400 vs 19,000 ppm), and consequently the desalination should be considerably less costly for the artesian water than for sea water. The fact that the wells will flow is also significant because of the potential saving on pumping costs.

Recharge area found in southwestern Florida

Test drilling in the Myakka River basin in southwestern Florida has revealed the presence of a fairly extensive area of ground-water recharge in the northeastern part of the basin. B. F. Joyner, Horace Sutcliffe, and H. N. Flippo report that recharge occurs principally where the land surface is 25 to 50 feet above sea level or higher. The aquifers recharged are in the Hawthorn and Tampa Formations, which in this area contain the water of best quality for domestic use.

Coastal canals and water management

From study of stream-discharge records C. B. Sherwood and Howard Klein conclude that the development of facilities to minimize the loss of water from coastal areas to the sea, through canals, will be a key factor in future water management in southeastern Florida. Records for the primary canals, available in the near-average year of 1964, indicate a mean annual discharge of more than 1.5 billion gallons daily. Much of this water could be salvaged by the addition of pumping facilities to move excess water from the coastal area into the inland water-conservation areas for release during the dry season. Studies of major well fields, which derive water from canals by induced infiltration, were made during recent drought periods. These studies indicate that water supplies for the entire population will be almost completely dependent on improved water-management practices in the near future.

CARIBBEAN REGION

Ground water in alluvial-fan deposits in Puerto Rico

A couple of hundred square miles of alluvium beneath the southern coastal plain of Puerto Rico, in places underlain by water-bearing limestone, yields the bulk of the more than 250 million gallons per day of ground water pumped in Puerto Rico. N. E. McClymonds and P. E. Ward (p. C231–C234), in studies designed to enable estimation of maximum practical rates of withdrawal in various segments of the plain, have made an intensive study of the alluvial fan of the Rio Nigua (Rio Salinas). The most permeable deposits were found to occupy two major troughs separated by a buried bedrock ridge. The study lead to preparation of a map showing the best areas for additional withdrawal.

Ground-water resources of southern Puerto Rico

Yields of water wells in the Tallaboa-Guayanilla-Yauco area of southern Puerto Rico locally exceed 1,000 gallons per minute, and I. G. Grossman (r2065) believes that moderate to large supplies are yet untapped. The chief aquifers are unconsolidated alluvium, but the widespread middle Tertiary Ponce Limestone, the only permeable bedrock aquifer in the region, also is productive, especially in valleys where solution has enlarged faults, joints, and bedding surfaces and where recharge is facilitated by overlying alluvium.

MIDCONTINENT AREA

Irregular distribution in time and space of the abundant water resources of the midcontinent area continues to be one of the principal water problems. Water-resources investigations, therefore, are directed not only to appraising the available water supplies but also to a better understanding of hydrologic systems and of the relationships of surface water and ground water that afford improved means of conserving, developing, and managing this resource. In addition many investigations are problem oriented in that they represent a response to an increasing list of critical problems such as salt-water encroachment, flooding, declining water levels, dilution of industrial and municipal wastes, and deterioration of chemical quality.

The discovery of previously unknown sources of water supply is a prime objective of water-resources appraisal studies. Undeveloped aquifers have been identified by test drilling in Harrison County, Miss., to a depth of 2,500 feet below sea level, where the previous deepest known source was 1,450 feet. New aquifers were discovered also in Jefferson Davis County, Miss., near Hibbing, Minn.; the Joplin area of Missouri; and the Jackson Purchase region of Kentucky.

Studies have revealed favorable conditions for artificially recharging ground-water aquifers in the Minneapolis–St. Paul area, Minnesota, and the Lansing area, Michigan. Induced recharge from streams to ground-water aquifers by properly located well fields is also hydrologically feasible in parts of the Great Miami and Scioto River basins, Ohio.

Rainfall-runoff relations, base-flow characteristics of streams, and draft-storage requirements of surface-water reservoirs are of increasing importance in overall management of the water resources. Segments of the programs in each of the midcontinent area States are directed to providing improved quality and quantity of basic hydrologic data and to their interpretation and analysis for development of water-storage and flood-control facilities and for coordinated use of ground- and surface-water resources.

Significant results of these and other current studies are reported below.

INTERSTATE STUDIES

Relationship of runoff to rainfall

Unit hydrographs developed by V. B. Sauer for 17 stream-gaging stations in southeastern Louisiana and southwestern Mississippi have been successfully regionalized into dimensionless terms so that synthetic unit hydrographs can be estimated for ungaged sites. Drainage-area size and lag time are the two parameters necessary. The more critical factor, lag time, can be estimated from formulas developed from the station data.

MINNESOTA

Aquifers in glacial deposits

Studies by G. F. Lindholm in the vicinity of Hibbing have revealed a buried valley entrenched in Cretaceous and Precambrian formations and filled with glaciofluvial sand and gravel deposits. The town of Hibbing obtains its water supply from some of these deposits, and subsurface mapping indicates other areas that are favorable for ground-water development.

L. H. Ropes has mapped deposits of glacial outwash sand and gravel near St. James that are potential sources of municipal water supply. Water from these deposits is of a better quality than that currently being developed from the deeper Cretaceous aquifer.

Bedrock aquifers in Twin Cities area

Previous and current studies in the Minneapolis–St. Paul area have identified problems related to concentrated pumping from wells, lowering of ground-water levels, and interaquifer movement of ground water. H. O. Reeder reports that an electric-analog model is now being built to aid in (1) prediction of future results of pumping, (2) determination of relations between surface water and ground water, and between aquifers, that influence natural recharge to aquifers, and (3) determination of the hydrologic feasibility of artificial recharge by means of recharge ponds and injection wells.

Hydrologic parameters for recreational use of streams

L. H. Ropes and Duane Wheat have discovered significant changes in the chemical quality of stream water as it enters impoundments on Minnesota streams. The significance of such changes on recreational use of streams is in their effect on variety and abundance of aquatic life in the lakes and streams. River profiles, flow velocities, and water depths are also useful for evaluating a stream's recreation potential. The study is designed to aid State conservation and recreation agencies in official classification of selected "wild rivers" as to their potential for various types of recreation.

WISCONSIN

Water loss and water quality, Root River Canal

R. D. Hutchinson is studying stream discharge and water quality in the Root River Canal, in Racine and Kenosha Counties in southeastern Wisconsin. Analysis of records for November 1963 shows that a 5-mile reach of the canal lost about 150,000 gallons per day to the ground-water reservoir. The canal carries a relatively heavy load of municipal and industrial wastes. The current study is also attacking the problem of potential pollution of the ground water as a result of this leakage from the canal.

Base-flow studies

Base-flow measurements of streams in the Fox River–Wolf River basin by P. G. Olcott show yields of 0.3 to 0.8 cubic feet per square mile from glacial outwash in the northern and western parts of the basin. By contrast, yields of less than 0.1 cfsm are contributed to streamflow by glacial-lake and ground-moraine deposits in the central and southeastern parts of the basin.

MICHIGAN

Potential for artificial recharge near Lansing

The increasing demand for water in the Lansing area has resulted in a progressive decline of water levels in the Pennsylvanian Saginaw Formation, the principal source of ground water in the area. Test drilling in the central and southeast part of the area revealed the presence of unsaturated permeable sand and gravel overlying unsaturated beds of sandstone which had been dewatered as a result of withdrawal of water from the Saginaw Formation. According to K. E. Vanlier and M. L. Wheeler the presence of unsaturated permeable material in contact with the sandstone indicates that artificial recharge of the sandstone may be possible through recharge pits. Surface water suitable for recharging is available for about 8 months of the year.

OHIO

Induced flow from Scioto River

S. E. Norris and R. E. Fidler report that wells completed in alluvial deposits of the Scioto River valley near Piketon, in south-central Ohio, are capable of yielding 10 million gallons per day of water from underground flow induced from the Scioto River. Development of this large ground-water supply, necessitated by deterioration of the surface-water quality, is expected to spur future additional development of this important water-course aquifer.

Ground-water potential in Miami River valley

A. M. Spieker reports that glacial outwash sand and gravel aquifers in the valley of the Great Miami River south of Dayton, in southwestern Ohio, can probably sustain from 2 to 3 times the present withdrawal rate of 100 million gallons per day, provided that future development is favorably located with respect to sources of recharge and away from the present centers of pumping (which are near Chautauqua, Franklin, Middletown, New Miami, Hamilton, Fairfield, and Ross). The most favorable areas for future development are near the major rivers in the vicinity of Trenton, between Fairfield and Ross, and in the lower Whitewater River valley south of Harrison. The only area of local overdraft is about 2 miles southeast of Middletown.

INDIANA

Ground water in southern Indiana

Studies by L. W. Cable and R. J. Wolf in Vanderburgh County and by T. M. Robison in Posey County indicate that unconsolidated sand and gravel deposits in the Ohio River valley are capable of yielding large volumes of ground water for industrial and municipal use. An underlying sandstone aquifer yields from 5 to 25 gallons per minute to wells, but is not capable of producing adequate supplies for large-scale use. J. D. Hunn reports that limestone aquifers yield only small supplies (5 to 20 gpm) in most of Harrison County. Small areas of alluvium exist along the Ohio River, but their potential for ground-water development has not yet been determined.

IOWA

Ground water in Muscatine Island area

Large quantities of water are available from the alluvial deposits in the Muscatine Island area of Muscatine County, in southeastern Iowa. R. E. Hansen reports that although pumpage from this 30-square-mile area (principally for municipal and industrial use) averages 34.5 million gallons per day, the amount of water in storage in the aquifer is estimated to be nearly 135 billion gallons. Wells located within 1 mile of the bordering Mississippi River obtain up to 70 percent of their water by induced infiltration. The quality of the water generally is very good, but iron does occur in objectionable quantities at several locations.

MISSOURI

Storage requirements for sustained reservoir outflow

John Skelton reports that the storage required to sustain a given draft rate varies markedly among the physiographic regions of Missouri. Draft rates that can be maintained by within-year storage range from 0.01–0.05 cubic feet per square mile in the plains area to 0.1–0.5 cfsm in the plateaus and southeast lowland. Analysis shows that for streams of comparable drainage area and 7-day annual minimum flow, about 20 percent more storage is required to sustain a given draft rate on a stream in the plains, during a drought of 20-year recurrence interval, than on streams in the other regions.

Ground water in Joplin area

Gerald Feder has found that considerably more water is available from Mississippian limestone in mineralized areas, both mined and unmined, than in surrounding areas of massive limestone known locally as "lime bars." The mineralized areas are those where solution has commonly removed much of the limestone, leaving a cemented chert breccia that has higher permeability than that of the massive limestone. The mineralized areas include both those rich and those poor in zinc. Yields of 1 to 10 gallons per minute may be expected from the massive limestone unless solution cavities along bedding planes or joints are found, whereas there is good probability of obtaining 50 to 100 gpm from wells in the unmined mineralized areas. Sustained pumping from individual mines for industrial use ranges from 100 to 1,000 gpm.

Large springs

A spring of first-order magnitude (average discharge more than 100 cubic feet per second), known to local residents but never before measured, was discovered to be one of the largest in the State, according to John Skelton. During a drought with a recurrence interval of 5 to 10 years the discharge was 68 cfs, as compared with 47 cfs from Double Spring, 500 feet distant, on the same day. The average discharge of Double Spring is 155 cfs; it seems likely that the average discharge of the new spring is higher. The importance of spring discharge to the streamflow is shown by a 150-percent increase in the flow of North Fork River in a reach of 500 feet, owing to the discharge of these two springs.

E. J. Harvey reports that springs issuing from Mississippian limestone on the Springfield Plateau in southwestern Missouri have higher nitrate content than springs on the Salem Plateau of central and eastern Missouri whose sources are in Ordovician and Cambrian dolomite and sandstone. Analysis of 390 samples shows that about 50 percent of the springs on the Springfield Plateau have more than 10 parts per million of nitrate, whereas only 3 percent of the springs on the Salem Plateau have more than 10 ppm of nitrate. The predominance of the higher nitrate content in spring water on the Springfield Plateau is believed due to the highly developed agricultural economy, where stock and dairy herds are more common and the use of fertilizer more widespread than on the more rugged terrain of the Salem Plateau.

KENTUCKY

Flushing out of saline ground water

Study by H. T. Hopkins of the interface between fresh water and saline water in the "salt sands" of the Lee Formation, in eastern Kentucky, suggests that brines have been flushed out. The original brines in parts of the region appear to have been flushed from the sands by fresh water moving downdip from the outcrop area toward zones of discharge that are along faults to the east and southeast.

Gravel aquifer discovered in Jackson Purchase region

Geologic and hydrologic studies by R. W. Davis, T. W. Lambert, and A. J. Hansen, Jr., in the Jackson Purchase region at the northern end of the Mississippi Embayment show that gravel deposits of Pliocene(?) and Pleistocene age, west of Paducah and extending several miles south of the Ohio River, are as thick as 93 feet and commonly contain ground water in the lower 30 to 40 feet. The gravels are a significant aquifer in this area, and properly constructed wells may yield as much as 1,000 gallons per minute for industrial or irrigation use.

ARKANSAS

Ground-water withdrawal from the Sparta Sand

D. R. Albin and others report that analysis of water levels in wells screened in the Sparta Sand of Eocene age, measured in southern Arkansas during the spring of 1965, indicates that (1) the cone of depression in the piezometric surface, caused by industrial pumpage at Pine Bluff, should stabilize by the year 1970 if current pumpage rates are not increased; and (2) cones of depression in the piezometric surface at El Dorado and Magnolia, originally well above the top of the aquifer, have declined nearly to the top of the aquifer. If continued decline should lead to partial dewatering of the Sparta Sand at El Dorado and Magnolia, increased rates of decline of well yields and a rise in pumping costs would result.

TENNESSEE

Quality of ground water at Memphis

Water in the "500-foot sand" in the Memphis area generally is soft and low in dissolved-solids content, but it is relatively high in iron and free carbon dioxide, and locally tends to be corrosive. In the southeastern part of the area the ground water has about 32 parts per million of dissolved solids and a hardness of 10 ppm; in the major center of pumping, 20 miles downgradient, dissolved solids amount to about 90 ppm and hardness 60 ppm. Water is migrating toward the centers of pumping at the rate of about 2 miles in 50 years, and the artesian head is declining 1 to 2 feet annually. E. A. Bell and D. J. Nyman conclude that the chemical quality of water will not change substantially within the next few decades, although slight variations in quality will result from changes in the direction and velocity of flow as the rates of pumping continue to increase and as new well fields are installed.

Water supply for Great Smoky Mountains National Park

The Precambrian metamorphic rocks in the vicinity of Great Smoky Mountains National Park headquarters generally cannot be expected to yield more than 10 gallons per minute to wells. In response to an increasing water demand, for which previously used springs were inadequate, studies were begun in December 1965 to locate additional supplies of ground water. W. M. McMaster reports that test drilling in the Gatlinburg fault zone has revealed a potential for greater yields from wells in the fault zone than in the adjacent rocks. A well, drilled to a depth of 150 feet, penetrated about 80 feet of the fault zone and yielded 70 gpm with drawdown of water level of about 30 feet.

ALABAMA

Saline ground water

K. D. Wahl has found an anomalous occurrence of saline ground water in Greene County, in west-central Alabama. The water has a hardness of 568 parts per million and contains as much as 3700 ppm of chloride. The mineralized ground water occurs in a southwestward-trending belt across the southern part of the county that is parallel to the trend of major folds and faults in Paleozoic rocks to the northeast. Data from adjacent counties indicate that this belt of mineralized water is 1 to 10 miles wide and can be traced a distance of about 60 miles, from central Tuscaloosa County southwestward across Hale and Greene Counties into Sumter County, where it merges with mineralized ground water associated with the Livingston fault zone.

MISSISSIPPI

Conversion of saline estuary to fresh-water reservoir

Studies by C. P. Humphreys, Jr., and W. L. Broussard reveal that a fresh-water reservoir is hydrologically feasible on the lower reaches of Old Fort Bayou, a saline estuary of Back Bay of Biloxi near Ocean Springs. Inflow is sufficient to maintain a conservation pool at the 5-foot elevation during a severe drought of 6-month duration. A consumptive draft of 2 million gallons per day, in addition to small-craft lockage, may be realized during a drought of this magnitude by drawing the reservoir down 1 foot; a 4-mgd supply may be obtained by drawing the reservoir down 2 feet. It is expected that a supply of about 8 mgd would be available in a normal year. Three to six months would be required during a normal year to freshen the reservoir to a chloride concentration of 250 parts per million, but as long as 18 to 24 months would be required during an extended drought. Freshening of water in the reservoir would be accompanied by changes in biota, partly as a result of the lowering of salt content of the water, and partly as a result of the increase in turbidity, which would affect light penetration and hence the growth of aquatic plants.

New aquifers discovered

Test drilling in Harrison County, along the Gulf coast in Mississippi, has revealed fresh-water aquifers at depths as great as 2,500 feet below sea level. According to D. E. Shattles the depth decreases to the north, west, and east of Gulfport but is less than 1,750 feet below sea level only in the extreme northeast corner of Harrison County. Prior to the test drilling the deepest known fresh-water aquifer was at 1,450 feet.

Test wells drilled in the Gulfport and Pass Christian areas resulted in the discovery of at least three major untapped aquifers capable of yielding several million gallons per day of water suitable for most industrial or municipal requirements. Each of the aquifers is more than 100 feet thick and each has sufficient pressure to force the water as high as 105 feet above the surface. The temperature of the water ranges from 92°F at 1,700 feet to 100°F at 2,500 feet. Chemical analyses indicate dissolved-solids concentrations of 716 parts per million for the deepest aquifer and 256 ppm for the shallowest.

R. E. Taylor reports that drilling at Carson, in Jefferson Davis County in south-central Mississippi, has revealed the presence of a new and potentially important aquifer. Further work is needed to determine its areal extent. The well taps coarse sand and gravel of Miocene age 260 feet below land surface, and an electric log indicates that the aquifer had not been completely penetrated when drilling ceased at a depth of 420 feet. An aquifer test indicated the transmissibility to be 480,000 gallons per day per foot. The specific capacity of the well is 70 gallons per minute per foot of drawdown. The presence of an aquifer having such characteristics was unsuspected prior to the drilling at Carson, for the transmissibility determined in the test is many times that ordinarily measured in the region.

Hydraulic efficiency at bridges

B. L. Neely, Jr., has studied flow characteristics at a bridge whose waterway area had been increased considerably by excavating between the highway right-of-way lines, and has concluded that excavation under the bridge increased the hydraulic efficiency of the channel. Comparison of measurements prior to and after excavation reveals increased discharge and reduced energy head required to pass the discharge. The study indicates that the maximum "effective" cross-sectional area of the excavation is approximately equal to the cross-sectional area around the lip of the excavation.

LOUISIANA

Structural control of salt-water encroachment

Test drilling in the Baton Rouge area, to locate salt-water fronts in the fresh-water aquifers that furnish public-supply and industrial water supplies, has resulted in identification of a fault that is limiting the northward migration of salt water. J. R. Rollo reports that the fault has displaced the "2,000-foot" sand as much as 350 feet downward, and that the hydraulic isolation of the aquifer south of the fault is confirmed by a head difference of 150 feet in a lateral distance of only 0.8 mile. However, the amount of offset diminishes upward and there is little or no displacement of the shallow aquifers (the "400-" and "600-foot" sands, principally), so that water in those aquifers is free to move northward toward pumping centers. Test drilling is continuing in order to establish the east-west extent of the faulting and to locate salt-water fronts in the shallow aquifers.

Saline ground water in southwestern Louisiana

Analysis of piezometric maps and water-quality data indicates that salt water in the Chicot aquifer, in the southern part of southwestern Louisiana, is moving northward towards areas of heavy pumping at rates that are generally much less than 100 feet per year. A. H. Harder, Chabot Kilburn, and S. M. Rogers conclude, as a result of this slow rate of movement, that the salt water presents no imminent danger to the fresh ground-water resources of southwestern Louisiana.

Scavenger-well system

R. A. Long (r0803) describes a successful test of a scavenger-well system in Ascension Parish, in southeastern Louisiana. The system, which recovers fresh water from the upper part of an aquifer that contains saline water in its basal part, consists of two wells: a shallower well, from which fresh water is pumped, and the deeper scavenger well which yields salty water. Pumping from the scavenger well prevents or retards flow of saline water upward through the aquifer to the shallow well. The chloride content of the water pumped from the shallow well can be controlled, within reasonable limits, by modification of the relative pumping rates of the two wells. A chief problem in use of the system is disposal of the saline water pumped from the scavenger well.

ROCKY MOUNTAIN AREA

Water studies being made in the Rocky Mountain area illustrate the diversity of water problems and the increasing variety of methods being employed by the U.S. Geological Survey in providing information for solution of these problems.

The source and character of the base flow and other low-flow features of streams become increasingly important, even in the more humid parts of the area, as water use increases. Keeping track of the effects of man's activities on water resources is still a significant part of the work, but forecasting the effects of possible alternate manipulations of the water resources constitutes a larger part of the work. Sources of salinity and other contaminants of streams, lakes, and ground waters must be found before they can be reduced or eliminated. Advances are continually being made in methods of investigation and analysis, such as use of digital computers, analog models, subsurface geophysical techniques, neutron moisture meters, and others. In addition, new sources of ground water, suitable in quality and sufficient in quantity for irrigation and municipal supply, continue to be discovered by the use of surface and subsurface geologic studies of traditional type.

The following discussion gives some idea of the studies now in progress in each of the 12 States in the area.

MONTANA

Deterioration in ground-water quality in parts of Glacier and Toole Counties

Studies by Everett Zimmerman in Glacier and Toole Counties, in northwestern Montana, indicate that ground water in the Virgelle Sandstone moves radially from a high outcrop area west of Sunburst toward points of natural discharge along the Virgelle escarpment, the canyon of Cut Bank Creek, and in Alberta, Canada. Changes in the quality of the water from several wells during the last 3 or 4 years suggest that drought and changing patterns of pumping have altered the direction of ground-water movement so that water of inferior quality from downdip or from zones of usually poor circulation enters some wells. The deterioration of water quality is temporary in some wells but may be permanent in others.

Ground water available in East Bench Irrigation Unit

A reconnaissance in parts of Beaverhead and Madison Counties, in southwestern Montana, by R. G. McMurtrey indicates that adequate ground water of suitable quality is available for domestic and stock-water supplies on new farm units in the East Bench Irrigation Unit. Depths of wells will range from 100 to 400 feet, depending on location and subsurface geology. Water adequate for irrigation use is available locally from the sediments underlying the flood plain of the Beaverhead River.

Ground water abundant in Kalispell Valley

R. L. Konizeski, Alex Brietkrietz, and R. G. McMurtrey have found, in a study of Kalispell Valley, in Flathead County in northwestern Montana, that a large quantity of ground water is available for municipal, irrigation, and industrial use. Some water-table wells yield as much as 2,000 gallons per minute. Extensive artesian aquifers are recharged by infiltration along the base of the marginal highlands. Most of the ground water is of good quality, although some shallow aquifers and the three principal streams draining the valley are subject to pollution.

NORTH DAKOTA

Electric-analog model predicts 1980 water levels in Minot area

Studies by W. A. Pettyjohn in the Minot area, in north-central North Dakota, reveal that about 56,000 acre-feet of ground water remains in storage and that at least 28,000 acre-feet has been removed. The Minot aquifer will provide only about 3 million gallons per day to wells without substantial water-level declines, but the city requires at least 4 mgd. It was suggested that artificial recharge would allow greater ground-water withdrawals. Computations by means of an electric-analog model of the aquifer indicate that under natural recharge conditions the predicted increases in municipal withdrawals will cause the water level to decline as much as 200 feet below land surface by 1980, but that the addition of 4.5 mgd of artificial recharge will raise the water to a level about 40 feet below land surface by the same date.

Ground-water storage in Divide County

C. A. Armstrong reports that 5 aquifers in parts of Divide County, in northwestern North Dakota, are capable of sustained yields ranging from 50 to more than 500 gallons per minute. The amounts of water stored in these aquifers are estimated (in acre feet) as follows: The Buried Yellowstone Channel aquifer, more than 800,000; the Skjermo Lake aquifer, more than 100,000; the Wildrose aquifer, about 190,000; and the West Wildrose aquifer, about 5,700. The Grenora aquifer probably contains as much water as the Buried Yellowstone Channel aquifer, but the Grenora aquifer extends beyond Divide County and much of the stored water underlies parts of northwestern Williams County and northeastern Montana.

Newly discovered buried channel

According to C. A. Armstrong, a buried former stream channel tentatively termed the Ray channel has been discovered in northwestern North Dakota. The channel, in eastern Williams County, is about 2 miles wide near Ray and widens to more than 3 miles southwest of Appam, where it joins the buried Yellowstone River valley. The altitude and trend of the Ray channel suggest that it may have been an ancient course of the Little Missouri River. The channel contains an aquifer that ranges in thickness from about 20 to 116 feet. In selected areas the aquifer may yield moderate quantities of water to properly constructed irrigation wells.

Glacial aquifers in Ward and Renville Counties

Test drilling and geologic studies in north-central North Dakota by W. A. Pettyjohn indicate that a considerable quantity of water is available in buried channels and outwash deposits in southern Ward County. The quality of the water ranges from very good to briny. A test hole in northwestern Renville County penetrated 705 feet of glacial drift, which is the thickest known glacial deposit in North Dakota.

Five major aquifers in Cass County

Geologic mapping and test drilling in Cass County, in southeastern North Dakota, have enabled R. L.

Klausing to delimit five major aquifers. The Fargo, West Fargo, and Page aquifers are buried outwash deposits capable of yielding 250 to 1,000 gallons per minute per well. Water levels in the West Fargo aquifer continue to decline; from November 1964 to November 1965 the maximum decline was 2.6 feet. The sand and silt deposits of the Sheyenne River delta probably are capable of yielding 200 to 500 gpm per well. The Dakota Sandstone, which underlies about three-fourths of the county at depths ranging from 400 to more than 900 feet, yields more than 600 million gallons of water per year for domestic, stock, and municipal use.

Four buried-valley aquifers in Wells County

Preliminary test drilling in Wells County, in the central part of the State, indicates four buried-valley aquifers, according to F. J. Buturla. Three of the aquifers in the southern half of the county trend generally northeastward, and contain from 20 to 100 feet of coarse sand and fine gravel. The aquifer in the northern half of the county trends generally northwestward, and contains from 100 to 140 feet of coarse sand and gravel.

Thick glacial deposits in eastern Grand Forks County

Test drilling has indicated to T. E. Kelly that much of eastern Grand Forks County is underlain by thick glacial deposits that lie directly on Paleozoic rocks. In most other parts of the county the Dakota Sandstone and Upper Cretaceous shales separate the Paleozoic strata from the glacial deposits. Deltaic deposits related to glacial Lake Agassiz, which are as much as 70 feet thick near the center of the delta, traverse the western part of the county from north to south. Chemical analyses of water indicate that many of the surficial aquifers have been contaminated by more highly mineralized water from the underlying Dakota Sandstone and Paleozoic rocks.

Buried outwash aquifer in northeastern Eddy County

Henry Trapp, Jr., reports that test drilling and well records reveal a southeast-trending buried channel containing one or more outwash aquifers. The channel extends from the vicinity of Hamar southeastward into Nelson County; it may be tributary to the Spiritwood channel, which has been traced northward from Barnes and Stutsman Counties to northwestern Griggs County. A water sample from a well in the channel southeast of Hamar contained only 383 parts per million of total solids, which is unusually low for water in buried outwash in this area. The aquifer may receive recharge nearby, either from the Sheyenne River or from surficial outwash.

Sheyenne delta a potential aquifer

The Sheyenne delta of glacial Lake Agassiz is one of the largest and potentially most productive shallow aquifers in Richland County, in southeastern Dakota, according to C. H. Baker, Jr. The delta covers an area of about 750 square miles, has an average thickness of more than 50 feet, and is estimated to contain more than 5 million acre-feet of recoverable water. The quality of the water is better than that in most shallow aquifers in the area; the total amount of dissolved solids averages about 500 parts per million. The average annual recharge may amount to more than half a million acre-feet. Present development of ground water from this aquifer is negligible.

Extent of aquifer in Traill County

According to H. M. Jensen test drilling of the aquifer that supplies the city of Hillsboro, in eastern North Dakota, reveals that it extends 10 miles north and 10 miles south of the city wells, and extends from the surface to a maximum known depth of 163 feet. The aquifer is U-shaped in cross section, consists mainly of fine to coarse sand, has a basal layer of pebbles and cobbles, and is bounded by till and lacustrine sediments.

WYOMING

Ground water in Wind River basin

Reconnaissance of the Wind River basin in west-central Wyoming by H. A. Whitcomb and M. E. Lowry reveals that supplies of stock and domestic water generally can be obtained from wells 100 to 300 feet deep drilled in Tertiary deposits (Wind River and Arikaree Formations) exposed over much of the basin, which has an area of about 10,000 square miles. Municipal and industrial supplies have been developed from wells 500 to 600 feet deep that yield 300 to 400 gallons per minute in some areas. Water in the Wind River Formation normally is under artesian pressure, but artesian heads generally are low and few wells flow. The chemical quality of water differs greatly throughout the area; the concentration of dissolved solids ranges from 500 to 4,500 parts per million. Water-table conditions prevail in the Arikaree, and depths to water are governed by the altitude of the land surface. Yields of wells are less than 100 gpm but are believed to be potentially greater. Water from the Arikaree generally contains less than 500 ppm of dissolved solids.

Supplies of water exceeding 400 gpm probably can be developed from the Tensleep Sandstone and the Madison Limestone, in or near areas of outcrop (principally along the western margin of the basin), and from alluvial deposits of major stream valleys. These sources remain largely untapped because supplies ample for current needs generally are available from shallower aquifers and perennial streams.

Piping in White River Formation

M. E. Lowry (p. D217–D222) presents evidence that high secondary permeability found locally in the Oligocene White River Formation is due to openings formed by piping. The openings in the formation, which is composed largely of siltstone, have previously been thought to be fractures. Many wells thought to tap the White River Formation probably obtain water from the overlying materials.

Streamflow in Pinedale area

Analysis by L. A. Wiard of streamflow data for the Pinedale area, in western Wyoming, for the 25-year period ending September 30, 1964, indicates that runoff volumes decrease sharply as streams from areas underlain by granite flow across the sediments and glacial deposits at the foot of the Wind River Range. Average annual yields of the adjacent drainage basins of Pine Creek, above Fremont Lake, and Pole Creek above the gaging station near Pinedale, were approximately 1,600 and 880 acre-feet per square mile, respectively. All the drainage basin of Pine Creek above Fremont Lake, and 75 percent of that of Pole Creek above the gaging station, are underlain by granite. Likewise, mean annual runoff to New Fork River from gaged headwater areas and tributaries (combined drainage area 237 square miles) was 265,000 acre-feet, as compared to 276,000 acre-feet for New Fork River above Boulder Creek (drainage area 552 square miles). Granite underlies approximately 75 percent of the combined tributary drainage basins, and about 40 percent of the New Fork River basin above Boulder Creek. Only part of the reduction in yield can be attributed to irrigation.

SOUTH DAKOTA

Water levels in South Dakota

D. G. Adolphson reports that 6 months to 3½ years of recorder records on 4 wells in pre-Cretaceous rocks in the Black Hills area show that there has been no continuing decrease or increase in artesian head, but that the head fluctuates with seasonal variations of precipitation and pumping for irrigation. Over the rest of the State, except in the southeastern part where the water level has remained fairly constant, there has been a slight decrease in the water level of wells in the Dakota Sandstone during the last 6 years.

Extensive aquifer in Clay County

An aquifer composed of outwash and alluvium underlies 80 percent of Clay County, in southeastern South Dakota. The aquifer has an average thickness of 100 feet, an average permeability of about 2,000 gallons per day per square foot, and supplies nearly 75 percent of the water used in the county, according to J. C. Stephens. The aquifer in the underlying Cretaceous Dakota Sandstone is a major source of recharge to the outwash-alluvial aquifer. The two aquifers are in contact in the bottom of a deep buried valley, where both aquifers contain water of nearly the same chemical composition. Movement of water into the overlying aquifer reduces the artesian head in the Dakota Sandstone and accounts for the absence of flowing wells on the Missouri River flood plain in southeastern Clay County.

Alluvium thin in Todd County

According to M. J. Ellis and D. G. Adolphson, test drilling in the Little White River valley and its tributaries indicates that the alluvium generally is thin, averaging about 25 feet in thickness. It consists of silty sand and sand in the southern part and clayey and silty sand in the northern part of the country.

Two main aquifers in Campbell County

N. C. Koch has found two main aquifers in Campbell County. A buried valley 200 to 400 feet deep, containing as much as 80 feet of sand and gravel, extends from the Oahe Reservoir westward to Pollock, east-southeastward to Herreid, and then southward east of Mound City. Water levels range from 30 to 60 feet below land surface. Water-level data indicate that the aquifer discharges water into the Oahe Reservoir. The city of Pollock has a well in this artesian aquifer that yields 250 gallons per minute. A shallow aquifer underlies Herreid and extends west and north of Spring Creek. Water levels in this aquifer, at Herreid, are within 6 feet of land surface.

Six aquifers in Bon Homme County

Studies by D. G. Jorgensen indicate six aquifers of economic importance in Bon Homme County in southeastern South Dakota. Outwash deposits along Choteau and Beaver Creeks and partly buried outwash which roughly parallels the course of Emanuel Creek comprise the three unconfined aquifers. The underlying Niobrara Formation, Codell Sandstone Member of Carlisle Shale, and Dakota Sandstone are artesian aquifers.

Bedrock aquifers recharged from Pleistocene drift

Preliminary analysis of data from east-central South Dakota by Lewis Howells indicates that aquifers in four Cretaceous units (Niobrara Formation, Codell Sandstone Member of the Carlisle Shale, Greenhorn Limestone, and Dakota Formation) and in the Precambrian Sioux Quartzite locally receive recharge from one or more aquifers in Pleistocene drift. The recharge, of water different in chemical character from that commonly found in the bedrock aquifers, probably has been induced by the great decline of artesian head in the bedrock, which amounts to 200 feet or more in the Dakota Formation.

Mixing of water types in Dakota Formation

E. F. LeRoux has found evidence of mixing of two types of water in the Dakota Formation north of the Sioux Ridge in southeastern South Dakota. Calcium sulfate water is found almost exclusively west and southwest of the Sioux Ridge, indicating a common source for recharge in these areas. Both sodium sulfate and sodium calcium sulfate waters occur in the area north of the Sioux Ridge. The sodium sulfate water is obtained from shallower wells in the Dakota; the mixed sodium calcium sulfate water generally is found in the deeper wells in the Dakota. This dual occurrence probably indicates a mixing of the calcium sulfate water from the west with sodium sulfate water from another source.

NEBRASKA

Productive Quaternary deposits in eastern Saunders County

According to V. L. Souders, Quaternary sand and gravel deposits in Todd Valley, in eastern Nebraska, contain an estimated 3.5 million acre-feet of water. The underlying Cretaceous Dakota Sandstone is hydraulically connected with the younger deposits in some places, and it may contain an additional 1.5 million acre-feet of water. The Quaternary deposits furnish water to nearly all the irrigation and municipal wells. Annual pumpage for irrigation has ranged from about 2,500 acre-feet in the wet year 1962 to about 6,000 acre-feet in the drought year 1957.

Effects of irrigation return on quality of streamflow

G. V. Gordon (p. C244–C250) reports that irrigation return flow probably was the main source of a 27-percent increase in the dissolved-solids content of water in the North Platte River during a period of low flow in the 60-mile reach between the Wyoming-Nebraska State line and Bridgeport. The effects of irrigation return were most apparent between the State line and Mitchell because stream flow was least in that part of the reach. Irrigation return from south of the river generally was of poorer quality than that from north of the river.

UTAH

Green River Formation a potential source of water in Uinta basin

According to R. D. Feltis, the Green River Formation contains fresh and slightly saline ground water on the south flank of the Uinta basin, and is a potential source of water for use in the development of oil shale and bituminous sandstone in that area.

Thick sediments underlie Skull Valley

J. W. Hood reports that Skull Valley, a structural depression directly tributary to the Great Salt Lake, is underlain by lacustrine and alluvial sediments of Tertiary and Quaternary age, probably several thousand feet thick. Of about half a million acre-feet of precipitation that falls on the valley annually, an estimated 30,000–50,000 acre-feet enters the ground-water reservoir. Most of the remaining water returns to the atmosphere, but a small amount may reach Great Salt Lake. Ground water in the upper end and edges of the valley is fresh to slightly saline; that in the center and lower end of the valley is slightly saline to briny. The poor quality may be due to the flushing of salts from the lacustrine sediments.

Artificial recharge possible in Juab Valley

L. J. Bjorklund reports that water levels in the northern Juab Valley have declined during the last decade because of the pumping of about 14,000 acre-feet annually from highly permeable alluvial fans along the east side of the valley. Canals to be constructed across these fans for importing water from the Central Utah Project could be used to recharge the aquifer, when water is available; ground-water levels generally lie more than 75 feet below the surface, and are about 150 feet below the surface near Nephi. Such recharge would increase the artesian head in the lower parts of the valley, thus increasing the discharge of springs and flowing wells, but water-logging and drainage problems in the rest of the valley could be minimized by continued heavy pumping for irrigation.

COLORADO

Ground water in Piceance Creek basin

Test drilling along the major drainages of the Piceance Creek basin in Rio Blanco and Garfield Counties indicates that the alluvium is as much as 130 feet thick and that the saturated thickness may be as much as 100 feet. According to D. L. Coffin and F. A. Welder, the measured transmissibility ranges from 40,000 to 155,000 gallons per day per foot, and the storage coefficient ranges from 0.002 to 0.20. Maximum well yields are estimated to be as much as 1,000 gallons per minute. Aquifer tests of the Parachute Creek Member of the Green River Formation indicate a transmissibility of 2,000 gpd per ft and a storage coefficient of 10^{-5}. Maximum well yields from this member are estimated to be as much as 1,000 gpm. The areal distribution of a fracture zone overlying a zone of saline minerals within the Parachute Creek Member has been delimited from electric logs.

Artesian aquifers in Grand Junction area

Studies of the geology and artesian water supply of the Grand Junction area by S. W. Lohman[14] revealed that three Mesozoic sandstone aquifers supply small amounts of water of good quality to flowing artesian wells. In order of productivity these are the Upper Jurassic Entrada Sandstone, the Upper Triassic Wingate Sandstone, and sandstone lenses in the Salt Wash Member of the Upper Jurassic Morrison Formation. A few wells obtain water from the Upper Cretaceous Dakota Sandstone and sandstones in the Lower Cretaceous Burro Canyon Formation, but the water generally is salty. Mutual interference between wells tapping the Entrada or the Entrada and Wingate reduced or stopped flow in many wells, necessitating the installation of pumps. Water was hauled to rural residents for domestic use until completion of a piped water system in October 1964, which imports water to the area from surface sources. The expected reduction in withdrawal from artesian wells should allow gradual recovery in artesian head.

KANSAS

Heavy withdrawal from ground-water storage

According to J. D. Winslow, study of electric-analog models is providing a better understanding of effects of the withdrawal of ground water from the thick Pliocene and Pleistocene aquifer in Grant and Stanton Counties. Ground-water levels have been declining there in recent years in response to increasingly heavy withdrawal of ground water for irrigation. Interpretations of a model of the area indicate that more than 90 percent of the water pumped is withdrawn from storage. Authorized annual appropriation of ground water in the two-county area was more than 500,000 acre-feet as of January 1, 1966.

Additional subsurface data in southwestern Kansas

R. C. Prill found, from the results of exploratory drilling during the summer of 1965 in Haskell and Stevens Counties, that in places the saturated thickness of unconsolidated Tertiary and Quaternary deposits is as much as 100 feet greater than previously known. This finding adds significantly to the known volume of the ground-water reservoir, an important consideration because irrigation with ground water is increasing in Stevens County, and most of the water is withdrawn from storage.

Prill also found, by subsurface correlation of radioactivity logs from oil and gas tests and test drilling in Kearny, Hamilton, Stanton, and Morton Counties, that the sandstone previously considered as Triassic is more likely of Jurassic age.

Neutron moisture meter traces recharge

By using a neutron moisture meter to trace the downward movement of moisture in dune sand in western Kansas, R. C. Prill found a relationship between depth of penetration and type of vegetation. The downward movement of moisture from 11 inches of rain that fell during a 36-day period in May and June 1965, was traced in 3 places having different vegetative cover. In sage-covered dunes, where roots reached depths of more than 16 feet, no moisture was observed to move below the root zone, and the moisture in the root zone apparently was removed by subsequent evapotranspiration. In grass-covered dunes, where roots reached a depth of about 9 feet, 1½ to 2 inches of moisture was observed to move below the root zone, and become available for ground-water recharge. In blowouts, virtually devoid of vegetation, about 10 inches of moisture was observed to move deep enough to recharge the ground-water reservoir.

ARIZONA

Ground water in Sacramento and Hualapai Valleys

More than 2,000 square miles of reconnaissance geologic mapping has been completed by J. B. Gillespie and C. B. Bentley in connection with a water-resources investigation in Mohave County in northwestern Arizona. More than 90 percent of the ground water in the area is stored in the alluvium-filled valleys. Transmissibilities of the alluvial aquifers average 20,000 to 30,000 gallons per day per foot. A reconnaissance seismic survey—recently completed by Richard Dodson, of the Branch of Astrogeology—showed that depths to water and to hard rock underlying the alluvium in the valleys can be determined by seismic methods.

Ground-water levels decline in Willcox basin

S. G. Brown and H. H. Schumann report that pumping for irrigation in the Willcox basin, in Graham and Cochise Counties in southeastern Arizona, exceeds

[14] S. W. Lohman, 1965, Geology and artesian water supply of the Grand Junction area, Colorado: U.S. Geol. Survey Prof. Paper 451, 149 p.

recharge by as much as 127,000 acre-feet per year. As a result, water levels have declined as much as 127 feet in the 12-year period 1952–64.

Coconino Sandstone most productive where fractured

The Permian Coconino Sandstone is the most important aquifer in southern Coconino County. Studies by E. H. McGavock and J. B. Gillespie indicate that fracturing may be an important factor in the yield and quality of water obtained from the Coconino. In the Flagstaff area, the Coconino generally yields less than 50 gallons per minute, but yields of more than 700 gpm have been obtained near major fault zones. Some wells penetrating a fracture zone near Winslow produce more than 1,000 gpm, in contrast to yields of 30 to 300 gpm in less fractured areas. However, the dissolved-solids content of water in the fractured zones has increased 50 to 100 percent in the last 3 to 10 years, whereas water quality in adjacent areas has remained unchanged for more than 30 years.

Water losses along East Verde River

E. S. Davidson and H. W. Hjalmarson have concluded that water losses to evapotranspiration and ground-water storage, from the 43-mile-long East Verde River in Gila County, will not increase greatly due to the addition of 30 to 50 cubic feet per second of water to the river near the headwaters. Their reasons are as follows: (1) most of the river is on relatively impermeable bedrock; (2) alluvium underlying reaches of the river channel and the flood plain probably is less than 30 feet thick and is usually saturated; (3) on the average the low flow of the river increases more than 3 cfs from near the head to the mouth; (4) the maximum net loss of water was only 0.5 cfs following a 2-month warm, dry period; and (5) evapotranspiration losses are fairly constant despite a rather large variation in streamflow.

Large seepage losses from small reservoirs

B. W. Thomsen found large seepage losses from two reservoirs that supply water for the city of Williams. Dogtown and Kaibab Reservoirs, with a combined storage capacity of 2,000 acre-feet, filled and spilled in April 1965 for the first time since 1952. By October 1965, seepage losses from the two reservoirs had amounted to 1,300 acre-feet.

Aquifers in and near delta of Colorado River

Studies by F. H. Olmstead, O. J. Loeltz, and Burdge Irelan have defined the character of the aquifer and the quality of ground water in the part of the Colorado River delta that lies within the United States. The aquifer underlies a roughly triangular area that has its apex at Laguna Dam, 15 miles north of Yuma. The area varies in width from 5 to 10 miles near the apex to more than 30 miles at the international boundary, 20 miles south of Yuma, and extends about 25 miles into Mexico. The thickness ranges from about 200 feet at the apex to about 3,000 feet near the international boundary. The most permeable materials, mainly alluvial sand and gravel, are in the upper 1,000 feet. The ground water moves southward, but the amount entering Mexico is believed to be small in relation to present recharge, which is principally from irrigation in the Colorado River valley and Yuma Mesa. The quality of ground water in most of the area is suitable for irrigation.

J. H. Robison has defined the general features of an extensive deltaic aquifer adjacent to the international boundary in Imperial County, Calif. It consists mainly of alluvial sand and gravel, ranges in thickness from about 600 to more than 2,000 feet, and is recharged by seepage from the Colorado River and the All-American and Coachella Canals.

Lower Colorado River geophysical exploration

D. R. Mabey, F. H. Olmstead, R. E. Mattick, and A. A. R. Zohdy report that gravity, seismic, magnetic, and resistivity methods of geophysical exploration were used to obtain subsurface data in support of ground-water investigations in the Yuma area. Each method contributed significant information to the investigation, and the integrated program of geophysical exploration substantially reduced the number of test holes required. Gravity data revealed the general configuration of the basement rock underlying the Cenozoic sediments and provided the approximate thickness of the sediments. Magnetic data indicated the presence of volcanic rocks interbedded with the sediments, and locally indicated the depth to basement and structure in the basement rock. The thickness of the unconsolidated sediments and locally the total thickness of sedimentary rock were determined by seismic-refraction soundings. Resistivity surveys provided data on the distribution of coarse and fine sediments and on the depth to basement.

NEW MEXICO

Ground water in Mescalero Apache Indian Reservation

According to C. E. Sloan, a recent well-drilling program on the Mescalero Apache Indian Reservation in the Sacramento Mountains indicated that small to moderate amounts of water can be obtained from sedimentary rocks of Permian to Late Cretaceous age. Of 19 wells drilled, 10 yielded more than 100 gallons per minute, 5 yielded 10 to 100 gpm, and 4 yielded less than 10 gpm. Depths of the wells ranged from 120 to 955 feet, and depths to water levels ranged from 60 to 800 feet. Total concentrations of dissolved solids ranged from 350 to 2,200 parts per million and averaged 745 ppm. Fourteen of the wells obtained moderate amounts of water containing less than 1,000 ppm of total dissolved solids from the Yeso Formation, the most widespread aquifer on the reservation. Two of the wells obtained more than 100 gpm of water containing less than 500 ppm of total dissolved solids from the San Andres Limestone, which crops out extensively in the reservation but is saturated only locally.

TEXAS

Base flow of Guadalupe River

In a study of the base flow of a 54-mile reach of the upper Guadalupe River, H. L. Kunze and J. T. Smith found that streamflow increased from about 0.1 cubic foot per second at the measuring site on the North Fork to 120 cfs in the main river at Comfort. Because of the different water-bearing properties of the aquifers crossed by the river and its tributaries, many localized gains and losses occurred in the reach studied. The principal tributary inflow was contributed by the Edwards Limestone and associated limestones. The Glen Rose Limestone contributed little water, and in some reaches water was lost to the Glen Rose. The dissolved solids in the water in the reach studied, largely calcium and magnesium bicarbonate, have concentrations ranging from 230 to 279 parts per million.

Salinity in upper Brazos River basin

A study by L. S. Hughes and M. W. Flugrath of sources of natural salinity in the upper Brazos River basin shows that low flows of most streams generally are saline but that seven tributaries are the principal sources of the sodium-chloride brine entering the Brazos River and degrading the quality of the water in Possum Kingdom Reservoir. The discharge-weighted average concentrations of dissolved solids, chloride, and sulfate in water released from the reservoir during the 8-year period 1957–64 were 1,020, 365, and 266 parts per million, respectively. If control measures being considered for the principal sources of salinity had been in effect during the 8-year period, the weighted averages would have been about 765, 229, and 212 ppm, respectively. This water would have compared favorably in quality with other supplies being used in western Texas for municipal, industrial, and agricultural purposes.

PACIFIC COAST AREA

The States of Alaska, California, Hawaii, Nevada, Idaho, Oregon, and Washington make up the Pacific coast area, and the last three constitute the Pacific Northwest. An area more diverse hydrologically would be difficult to find. Elevations range from 280 feet below sea level in Death Valley, Calif., to 20,300 feet above sea level on Mount McKinley, Alaska. Precipitation spans the range from near zero in some desert areas to more than 400 inches annually in the mountains of Hawaii. Stream runoff ranges from periods of zero flow for many rivers in the arid areas to more than 1 million cubic feet per second in both the Columbia and Yukon Rivers. Water problems are giving rise to a growing concern throughout the region. One of the chief concerns is that people want to live in areas where the climate is warm and dry the year round, and it is in these areas that water shortages are increasing. Associated problems include increase of dissolved solids because of irrigation return flows, withdrawal of ground water in excess of recharge rates, permafrost, and lack of sufficient water locally to supply the increased population and industrial expansion.

Basic data on streamflow, ground-water levels, chemical quality, water temperature, and sediment transport have been collected for many years, and some streamflow records are continuous for more than 75 years. Since 1950, surface water used for irrigation has been monitored by a network of chemical-quality stations to detect long-term changes in quality. The basic-data program is continually being reviewed, added to, and changed to meet the needs for water facts. Key hydrologic bench marks have been established in areas, where, during the next 50 years or more, man's activity is expected to have little or no influence on the hydrologic cycle. Data collected at these bench-mark stations should reflect any significant long-term natural changes which occur in response to climatic changes. Studies of the natural hydrologic changes should assist hydrologists in prediction of the changes likely to occur when man's activities are superimposed upon the natural regimen.

Investigations by the Water Resources Division are designed both to provide bases for the solution of water problems and to uncover basic facts that apply to the hydrologic cycle. These investigations include study of the low flow of streams, faults as barriers to the movement of ground water, the quality of estuarine waters, the influence of different methods of logging on rates of sediment transport, and the use of surface water to recharge ground-water aquifers.

Glaciers are being studied to determine their response to climate and their influence on streamflow, and to discover whether they can be managed for man's benefit. Useless water-consuming plants (phreatophytes) are being studied to find out how much water they waste and how this use affects the ground water. Examples of investigations are given below. In addition, the reader is referred to the list of water-resources investigations in progress for the States of the Pacific coast area (p. A251).

INTERSTATE STUDIES

Ground-water quality in the Great Basin

The Great Basin, which includes most of Nevada and parts of California, Utah, Oregon, Idaho, and Wyoming, has long been a region of interior drainage and salt accumulation. In a reconnaissance of the quality of ground water J. H. Feth (p. D237–D241) has found, however, that virtually all valleys in the region produce some potable ground water. The water suitable for domestic use is commonly of the calcium magnesium bicarbonate, calcium sodium bicarbonate, or sodium bicarbonate types. The highly mineralized waters, commonly of sodium sulfate and sodium chloride types, include the brines and other saline waters for which the region is famous.

ALASKA

Ground water limited on Annette Island

Studies made by M. V. Marcher on Annette Island in southeastern Alaska indicate that supplies of ground water are limited. The results of test drilling in nearly impermeable igneous rocks underlying the island suggest that thrust-fault breccias are probably the main water-bearing zones. A well drilled by the Federal Aviation Agency in the vicinity of the airport yielded 100 gallons per minute when first completed, but production was reduced to 25 gpm to prevent salt-water intrusion.

Water supply in a permafrost region

A. J. Feulner and J. R. Williams report that thawing as a result of construction activity at Cape Lisburne, in northwestern Alaska, modified the thermal regime of the ground significantly. As a result, a gallery under Caribou Creek supplied enough water to meet the needs of a U.S. Air Force installation during most of the following winter. A cover of soil and vegetation was stripped from areas near the creek in connection with road construction. The more effective heating by the sun thawed gravel, previously perennially frozen, to such an extent that an infiltration gallery in the creek bottom provided water from the time of autumn freezeup of the creek until about February. During that period the gallery produced water to meet current needs, and also for storage in heated tanks that later sufficed to supply the installation until the spring thaw restored the flow of water in the creek.

Reports on hydrologic effects of Alaska earthquake

Detailed reports of effects of the 1964 earthquake on the hydrology of south-central Alaska and on the Anchorage area have been completed by R. M. Waller. Widespread changes in water levels in wells followed the tremors immediately. In some wells the water surface returned to the prequake level within a few days to a few months, but in the majority of wells the water level recovered much more slowly. In many places where the water table in unconsolidated materials was near land surface, momentary spouts of sand and mud developed, typically from linear fissures. Changes in ground-water quality were (1) temporary turbidity, which was common, and (2) chemical changes in areas where regional subsidence allowed sea water to invade lowlying areas. Changes in the physical structure of some aquifers in the Anchorage area are suspected but cannot be incontrovertibly demonstrated. Regional subsidence, which amounted to about 2 feet near Anchorage, probably modified points of discharge of ground water from aquifers that extend under Cook Inlet. These changes may have increased the likelihood of sea-water intrusion locally.

PACIFIC NORTHWEST

Ground-water levels decline in Raft River basin, Idaho

Studies in progress by E. H. Walker indicate that pumping of ground water for irrigation in the Raft River valley of southern Idaho has lowered water levels 15 feet or more over an area of almost 100 square miles since substantial ground-water development began in the early 1950's, and from 25 feet to more than 40 feet over 30 square miles. It is estimated that the amount of water in the underground reservoir has been reduced by 200,000 to 270,000 acre-feet.

Increasing use of ground water in Snake River Plain

Irrigation with ground water pumped from the Snake River Plain of southern Idaho has expanded greatly since the 1940's. According to E. H. Walker, the area irrigated with water from wells increased from about 30,000 acres in 1940 to 330,000 acres in 1960, and probably to about 500,000 acres in 1965. The consumption of pumped ground water is estimated to have been about 700,000 acre-feet in 1965, which is about 10 percent of the total discharge from the aquifer by springs before irrigation with ground water began to expand rapidly. The flow of the springs will eventually decline by an amount equal to the consumption of ground water, which will exceed 700,000 acre-feet a year because irrigation with ground water continues to expand, although at a lesser rate than before 1960.

Aquifers in buried outwash deposits in Washington

Recent studies by H. W. Anderson, Jr., in the Coulee Dam National Recreation area of northeastern Washington have revealed that several hundred gallons per minute of water is available from alluvial fans or glacial outwash buried beneath the Nespelem Silt, which was deposited in glacial Lake Columbia during middle Pinedale time. Two test wells drilled near the shore of Franklin D. Roosevelt Lake, at the mouths of tributary canyons, each penetrated more than 100 feet of fine-grained glacial-lake deposits before entering alluvial sand and gravel. Each well has a specific capacity of 10 to 15 gallons per minute per foot of drawdown.

Ground water in Spokane and Stevens Counties, Wash.

D. R. Cline has found a great range in availability of ground water in a small basin surrounded by mountains in northern Spokane and southeastern Stevens Counties, in eastern Washington. The granitic rocks, which have large relief and crop out in many places, yield small supplies—enough for domestic and stock use—or none at all. Interbedded sequences of Yakima(?) Basalt flows and lake clay and sand of the Latah Formation, which overlie the granitic rocks, generally also yield small amounts of water to wells. Glacial-lake deposits yield small to moderate amounts of water—as much as several hundred gallons per minute. Glacial-stream deposits in the valleys of the Spokane and lower Little Spokane Rivers yield large amounts of water—commonly several thousand gallons per minute with only a few feet of drawdown.

Three chemical types of ground water in Island County, Wash.

A. S. Van Denburgh reports that the ground water of Island County, Wash., is of three different chemical types. Most of the ground water in southern Whidbey Island and in the uplands of Camano Island has less than 300 parts per million of dissolved solids. In contrast, a more saline ground water characterized by 300 to more than a 1,000 ppm of dissolved solids and 180 to more than 800 ppm of hardness is common in northern Whidbey Island and northeastern Camano Island. At places adjacent to Puget Sound where sea-water encroachment has occurred, water of one of these types has been changed to a third, more saline type.

Sea-water intrusion in the Duwamish River, Wash.

Analysis of continuous specific-conductance data from the Duwamish River at East Marginal Way, Seattle, has revealed that the movement of sea water upstream beyond that point depends on the tide stage and on the rate of stream discharge. According to J. D. Stoner, intrusion occurs whenever the fresh-water discharge is less than 600 cubic feet per second, and does not occur at any tide stage when the discharge is greater than 1,000 cfs. Whether sea water moves upstream beyond this station when stream discharge is between 600 and 1,000 cfs depends entirely on tide stage.

Ground water in Adams County, Wash.

The use of ground water for irrigation in central and eastern Adams County, in southeastern Washington, has been increasing since about 1962. According to J. W. Bingham, wells in the area yield as much as 1,800 gallons per minute. Most of the larger yields are obtained from basalt aquifers 500 to 900 feet below the surface. Some wells drilled to those depths, however, do not yield an adequate irrigation supply; evidently the permeability of the aquifers is rather variable. Small-diameter wells for domestic use, drilled to basalt aquifers less than 300 feet below the surface, yield less than 50 gpm. In some areas where the shallow wells are within a few hundred feet of deep irrigation wells, the water levels in the shallow wells have been slowly declining.

New aquifer in North Powder Valley, Oreg.

D. J. Lystrom and E. R. Hampton have discovered a previously unknown aquifer in thick upper Tertiary valley fill in the North Powder Valley in eastern Oregon. The aquifer consists of beds of granitic sand and grit that make up more than half the 400-foot-thick unit of claystone, tuff, shale, sand, grit, and gravel. Two wells which tap this aquifer each yield more than 1,000 gallons per minute. Prior to these studies, the North Powder Valley was thought to be underlain by terrace gravels atop a thin sequence of interbedded tuffs and basaltic lava flows that in turn overlie metamorphic bedrock.

Summary of water resources in Washington

Current knowledge of the water resources of Washington has been summarized in a report (U.S. Geol. Survey, r2066) prepared by the Geological Survey in collaboration with the Washington State Department of Conservation, Division of Mines and Geology,

230-568 O-67—4

the U.S. Bureau of Reclamation, and other agencies. The discussion considers ground-water resources in areas in the State; surface water in the principal river basins; lakes, reservoirs, and glaciers; the quality of the surface water; and water use and water problems.

CALIFORNIA

Runoff from coastal basins

Runoff responds rapidly to rainfall in the coastal basins of California between San Francisco Bay and the Eel River. S. E. Rantz and T. H. Thompson attribute this to the fact that infiltration is inhibited by the low permeability of the soil and surficial rock and by the limited capacity for subsurface storage in most of the region. Storm-runoff intensity and volume for various durations and frequencies were found to correlate closely with drainage area and mean annual precipitation.

Ground water at the Marine Corps Supply Center, Barstow

Studies by G. A. Miller indicate that the quantity of ground water in the Barstow and Yermo subbasins of the Mojave River basin is adequate to meet the needs of the Marine Corps Supply Center for several years. Ground water for use in the Center is pumped from both subbasins, but that from the Yermo subbasin is preferable; the chemical quality of the ground water in the Barstow subbasin has deteriorated significantly since 1940, whereas the quality of ground water from the Yermo subbasin has remained practically constant. Seepage during infrequent and irregularly spaced floods on the Mojave River, which heads in the San Bernardino Mountains and is normally dry in the Barstow area, furnishes much of the recharge to the ground-water basins. During the period 1930–65, the average annual surface flow past Barstow and into the area was about 17,000 acre-feet. However, during the dry part of this period, 1946–65, the average flow was less than 2,000 acre-feet.

Deterioration of quality of ground water in the Hopland Indian Rancheria

A reconnaissance by J. P. Akers indicates that the quality of ground water used at the Hopland Indian Rancheria, in northern California, has progressively deteriorated as a result of contamination by carbon dioxide and mineralized water, which are believed to be coming from a zone of volcanism at depth. The Rancheria is underlain in part by alluvium in which there is a persistent clay bed that confines the mineralized water containing the carbon dioxide. Water in the alluvium above the clay bed is of good quality. Thin or sandy phases of the clay bed, and wells that penetrate it, have allowed the carbon dioxide and mineralized water to move upward into the alluvium locally. Ground water of good quality for the Rancheria probably can be developed from new wells in the alluvium above the clay after present wells are sealed or from infiltration galleries in channel deposits beneath streams.

Water at Point Reyes National Seashore

R. H. Dale and S. E. Rantz report that the principal rocks of the Seashore area, with reference to the occurrence of ground waer, consist of a basement complex overlain by marine sandstone and by shale and mudstone which, in turn, are overlain by terrace and dune sand, alluvial sand and gravel, and tidal-marsh clay and silt. Wells completed in the basement complex, the shale and mudstone, and the clay and silt yield about 1 gallon per minute; in the sandstone and the terrace and dune sand, about 10 gpm; and in the sand and gravel, as much as 60 gpm. Supplies of less than 5 gpm can be developed at most sites proposed for visitor accommodations, but quantities in excess of 25 gpm will be difficult to develop. Three test wells completed in clayey sand near Point Reyes Beach had yields ranging from 5 to 20 gpm—adequate to supply proposed visitor accommodations nearby. Summer streamflow generally is inadequate to supply visitor accommodations at beach sites north of the latitude of the western tip of Point Reyes peninsula, but is adequate at other proposed visitor sites.

Ground-water quality at Fresno related to depth

Ground water in the Fresno area is generally of good quality for both irrigation and domestic use. Studies by R. W. Page and R. A. LeBlanc show, however, that in the extreme western part of the area the percent sodium in ground water increases abruptly from about 30 to 40 percent to about 80 to 90 percent. The high-sodium water is unsuitable for irrigating fine-textured soils. In addition, the dissolved-solids content of ground water at depth approaches or exceeds 2,000 parts per million, and this content varies with depth. The depth to the poorer quality ground water in the Fresno area ranges from about 700 feet in the northwestern part of the area to about 3,000 feet in the southern part.

Ground water in Pinnacles National Monument

J. P. Akers reports that test wells drilled in volcanic and metamorphic rocks in the western part of Pinnacles National Monument obtained artesian flows of about 15 gallons per minute, sufficient to supply the needs of a proposed public campground. Reconnaissance of the eastern part of the monument area indicates that considerable quantities of water are discharged from springs along a fault in the Temblor Formation, a Miocene fanglomerate. The Temblor has good potential for supplying water for camp facilities in the eastern part of the monument.

Ground water at Vandenberg Air Force Base

According to S. G. Robson and F. W. Giessner, studies of water levels in the South Vandenberg area of Vandenberg Air Force Base indicate no significant change in the quantity of ground water in storage. Chemical analyses of ground water samples indicate that the quality has not deteriorated appreciably and that sea-water intrusion is not occurring.

Potential for salt-water intrusion near Huntington Beach

J. R. Wall, E. H. Cordes, and J. A. Moreland report that stratigraphic studies of Recent and upper Pleistocene sediments in the Huntington Beach area, in Orange County in southern California, have shown the sedimentary sequence to be an extremely variable accumulation of sand, silt, clay, and gravel. Construction of saline-water channels may cause deterioration in the quality of ground water because there are few, if any, thick and extensive beds of impermeable deposits that would serve as barriers to salt-water intrusion.

Ground-water conditions at Twentynine Palms

The water supply for the U.S. Marine Corps Base, Twentynine Palms, Calif., is ground water pumped from wells, and the withdrawal is estimated at about 2,200 acre-feet for the 1966 fiscal year, according to F. W. Giessner and J. A. Westphal. Water-level records show that the pumping has no appreciable effect on water levels in the area.

NEVADA

Ground-water barrier in Pershing County

With the aid of a gravity study by D. R. Mabey, R. E. Wallace interpreted the Harrison Spring fault in Buena Vista Valley to be an important ground-water barrier. Many unsuccessful wells had been sunk east of the fault, one to a depth of slightly more than 1,000 feet. Two wells have now been developed west of the fault by ranches; one reportedly produces 3,200 gallons per minute from a depth of 126 feet, and the other 3,800 gpm from 157 feet.

Reconnaissance ground-water studies

Reconnaissance ground-water studies have been completed or were in progress in 12 valleys during the year. Preliminary estimates of sustained yield, based on estimates of annual recharge to, and discharge from, the ground-water reservoir for several of the valleys, are as follows: 80,000 acre-feet for Snake Valley, Nevada and Utah (J. W. Hood and F. E. Rush, r2020); a few hundred acre-feet for Eldorado–Piute Valley, Nevada and California (F. E. Rush and C. J. Huxel, Jr., r0023); 13,000 acre-feet for Carico Lake Valley, Lander County (D. E. Everett and F. E. Rush, r0556); 500 acre-feet for Eldorado Valley, Clark County; 70,000 acre-feet for Steptoe Valley, White Pine County; 10,000 acre-feet for Little Fish Lake Valley, Nye County; 6,000 acre-feet for Hot Creek Valley, Nye County; 5,000 acre-feet for southern Little Smoky Valley, Nye County; and 1,000 acre-feet for northern Little Smoky Valley, Nye County. The preliminary estimate of sustained yield of the entire hydrologic system in Huntington Valley, Elko and White Pine Counties, is 150,000 acre-feet (F. E. Rush and D. E. Everett, r2037). Eldorado, Little Fish Lake, and southern Little Smoky Valley, though topographically closed basins, lose ground water by underflow.

Chemical-quality study of Walker Lake

D. E. Everett reports that chemical analyses of water samples collected from Walker Lake show the water to be uniform throughout with respect to dissolved solids. Samples were collected during October 1965 from 8 locations and from several depths ranging from 5 to 125 feet. Specific conductance for all samples varied but slightly from 11,800 microhms. The predominant ions are sodium, chloride, and sulfate.

Ground-water pumpage in Diamond Valley

Annual pumpage of ground water for irrigation in Diamond Valley, in Eureka and Elko Counties in northeastern Nevada, has increased from 6,000 acre-feet in 1961 to 16,000 acre-feet in 1965, according to a study made by James Harrill. An estimated total of 64,000 acre-feet of ground water has been pumped from storage since development of the area began in 1960.

Hydrology of Humboldt River basin

From a reconnaissance of the 17,000-square-mile Humboldt River basin in northern Nevada, T. E. Eakin and R. D. Lamke estimate that the average annual volume of precipitation is of the order of 9.4 million acre-feet, which is equivalent to a little more than 10 inches over the entire basin. The range in annual volumes, from as little as 3.5 million acre-feet to as much as 17 million acre-feet, reflects substantial year-to-year variations in precipitation. Annual runoff from the mountain areas is estimated to range from 0.3 to 1.8 million acre-feet and to average about 0.85 million acre-feet. Short-term natural variations of ground-water storage in the saturated deposits beneath the flood plain of the Humboldt River and its principal tributaries, from extreme low levels to extreme high levels, may be as much as 500,000 acre-feet.[15]

Ground-water conditions in Mason Valley

C. J. Huxel, Jr., estimates the long-term average annual inflow to the ground-water reservoir in Mason Valley, in Lyon County in western Nevada, to be about 75,000 acre-feet. Most of the inflow is seepage from the East Walker and West Walker Rivers or from water diverted from the rivers for irrigation; only about 5 to 10 percent of the inflow is derived from local precipitation. The transmissibility of the valley-fill aquifer ranges from 50,000 to 250,000 gallons per day per foot.

HAWAII

Use of electrical resistivity in ground-water studies

A. A. R. Zohdy and Dallas Jackson report the use of electrical-resistivity soundings on the island of Oahu to delineate areas with saline, brackish, and fresh ground water. The interpretations are based on geologic cross sections, isopach maps, and a structure-contour map, as well as vertical electrical soundings and records of the few wells in the areas studied.

On the island of Hawaii, 4 deep electrical-resistivity soundings have indicated the possible presence of large quantities of fresh ground water at a depth of about 2,000 feet from the surface, according to Zohdy and Jackson. A well drilled to a depth of 1,000 feet, prior to the resistivity measurements, proved to be dry.

Ground water on Kilauea

In the area north of the east rift zone of Kilauea volcano, abundant rain falls on a highly permeable lava terrane. Part of the infiltrated water becomes perched on soil or ash beds intercalated in lavas, and feeds high-level springs, but most of it moves down to the basal water table, a few feet above sea level, and eventually discharges into the sea at springs along the shore. According to George Yamanaga and D. A. Davis, water in the basal ground-water body appears ample for any foreseeable demands; however, development generally would be costly, except in coastal areas, because of great depths to the water table and high pumping heads. High-level springs and artificial catchment of rainfall are potential sources of water; however, storage would be needed for dependable large supplies, owing to fluctuations in flow and rainfall. South of the rift zone, where the rainfall is less, the basal water supply is smaller and, because of the comparatively small flow of fresh water to the sea, salt-water encroachment affects wider zones along the coast.

Ground water in the Kahuku area, Oahu

Studies by K. J. Takasaki and Santos Valenciano show that large quantities of ground water discharge into the sea in northeastern Oahu, but that over a period of many years heavy pumping for irrigation of sugarcane has resulted in local overdraft, sea-water intrusion, and some consequent deterioration in the quality of the water. The total ground-water recharge in the area is estimated to be about 80 million gallons per day, and the total pumpage about 30 mgd. Approximately two-thirds of the pumpage is in the Kahuku section of the area, where the draft exceeds the local recharge and where substantial increases in salinity have occurred.

Hydrologic cycle in north-central Oahu

The 148-square-mile Mokuleia-Waialua area in north-central Oahu has an average annual rainfall of about 550 million gallons per day. J. C. Rosenau, E. R. Lubke, and R. H. Nakahara have found that recharge from rainfall and irrigation water probably exceeds 200 mgd. Water use in a relatively dry year approaches 93 million gallons per day, of which more than 80 percent is used for the irrigation of sugarcane. Direct runoff to the sea occurs only in response to intense or prolonged heavy rainfall. Natural discharge from the basaltic aquifer is at shoreline springs and submarine springs, and by leakage into the overlying coastal alluvium.

Withdrawal of ground water increasing near Pearl Harbor

About 25,000 acres of irrigated sugarcane land was developed adjacent to the Pearl Harbor area by 1900. Since 1940 the total sugarcane acreage has been reduced by 20 percent because of conversion of the land to military and residential use. R. H. Dale has found that although there was a decrease in the irrigated sugarcane acreage between 1940 and 1965, net withdrawals of ground water increased by 25 percent.

[15] T. E. Eakin and R. D. Lamke, in press, A hydrologic reconnaissance of the Humboldt River basin: Nevada Dept. Conserv. and Nat. Resources Water Resources Bull. 24.

MANAGEMENT OF NATURAL RESOURCES ON THE PUBLIC LAND

The functions of the Conservation Division of the U.S. Geological Survey relate to Federal lands, and to minerals on them which are leasable under the Mineral Leasing Act of 1920, as amended; and to the preservation of public-land reservoir sites to assure their availability, as needed, for future water-resources development. The objectives of Conservation Division activities are primarily the conservation of natural resources by authorized Federal control of their efficient and timely development, their maximum utilization, and their disposal. The Division evaluates and classifies Federal lands for leasable minerals and for sites for reservoirs and hydroelectric power development. It supervises the prospecting, development, and production of leasable minerals on Federal lands. And it computes, collects, and accounts for royalties so that the Government receives a fair return from the marketing of leased mineral resources. Related functions are performed for some Indian lands.

Field offices of the Division are listed on page A217. Geologic and hydrologic work in progress by geologists and engineers of the Conservation Division is given in the list of investigations starting on page A223, under the categories of geologic mapping, glaciology, waterpower classification, and various commodities such as coal and petroleum and natural gas. Scientific and economic results of these investigations are published as books and maps in the regular series of Geological Survey publications. Important scientific findings of current interest by Division geologists are included in the section "Regional Geology."

CLASSIFICATION OF MINERAL LANDS

The Organic Act creating the U.S. Geological Survey charged the Director with the responsibility of classifying the lands of the public domain. In order to prevent alienation of valuable mineral lands not subject to the general mining laws, large areas of potential nonmetallic mineral lands were withdrawn and may not be disposed of without a reservation of mineral rights to the government. These lands have been systematically investigated geologically and evaluated for their mineral potential.

Mineral-land classification consists of determination of (1) the mineral or nonmineral character of the Federal lands, and (2) the quality, thickness, and depth of the mineral deposits. Geologic data on leasable minerals on the Federal lands are obtained from all sources, including detailed mapping and sampling by Division geologists. Because of continual changes in geologic knowledge, in mineral technology, and in land use, the criteria used in the classification work are continually reappraised and revised to give updated resource evaluations.

Mineral-land classification implements provisions of the Mineral Leasing Act, reserving title to the Government in such energy resources as coal, oil, gas, oil shale, asphalt, and bituminous sands, and in fertilizer and industrial minerals such as phosphate, potash, sodium, and sulfur on public lands. All minerals on acquired lands are subject to the Mineral Leasing Act. At present about 53 million acres of withdrawn or prospectively valuable mineral lands require classification for leasable minerals. Areas are also classified for competitive or noncompetitive mineral lease or permit. More than 30,000 lease applications are reported on each year.

Determinations of mineral potential are made, on request by executive agencies, on specific tracts of Federal lands under the supervision of the agencies, and classifications and recommendations are made for their guidance. Nearly 8,000 such reports were made to other Federal agencies in 1966.

New geologic quadrangle maps prepared for classification purposes are published in the standard map series of the Geological Survey.

WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES

The program of the U.S. Geological Survey to classify and preserve public-land reservoir sites dates back to 1888, when Congress authorized the segregation of sites for the impoundment of irrigation water. In 1909, emphasis turned to preservation and segregation of sites with a potential for the development of hydroelectric power. Today the objective of this program is to identify, classify, analyze the potential of, and segregate from disposal or adverse use, all reservoir sites on the public lands.

The program includes (1) stream-basin investigations and cooperative agreements to provide land-administering agencies with information needed for land disposal and multiple-use management; and (2) continuing review of previous classifications, as more reliable streamflow and topographic data become available, as technology changes, and as alternative river developments are undertaken. Many early classifications are being revised, and much land is returned to the unencumbered public domain for disposition or multiple-use management. During fiscal year 1966 the review of 126,000 acres of land withdrawn for waterpower use was completed.

The Branch of Waterpower Classification conducts a limited specialized mapping program, largely confined to sites in Alaska, to aid water-resources classification of areas not covered by maps of standard accuracy in the topographic-quadrangle series. River and land basins are mapped at a scale of 1:24,000, and contours of lake bottoms are compiled by precise sounding surveys.

Grinnell and Sperry Glaciers in Glacier National Park, Mont.; Nisqually Glacier in Mt. Ranier National Park, Wash. and Barrier Glacier, near Mt. Spurr, in Alaska, are measured each summer from permanent control points to determine rate of movement, ablation, and recession or advance.

SUPERVISION OF PROSPECTING, DEVELOPMENT, AND RECOVERY OF MINERALS

Supervision of exploration, prospecting, development, and recovery of leasable minerals in deposits on Federal lands by the U.S. Geological Survey begins with engineering investigation of deposits under application for leases or permits for oil, gas, or minerals. It includes enforcement of lease terms and operating regulations to insure the efficient development and maximum recovery of deposits, the protection of other land resources, and the safety of workmen. Supervision also includes verification of production, and determination and collection of royalties. The Conservation Division acts as an advisor to the Secretary of the Interior, to other bureaus of the Department, and to other Government agencies concerned with various aspects of the administration of the Mineral Leasing Laws.

Royalties from public lands are distributed in the following proportions: 52½ percent to the reclamation fund, 37½ percent to the States in which the minerals or fuels are produced (except Alaska, which receives 90 percent), and 10 percent to the Federal Treasury. Royalties from other land categories are distributed in many different ways as provided by law. Oil, gas, and sulfur royalties from the Outer Continental Shelf, constituting more than half of all Federal-land mineral royalties in 1966, are returned directly to the Federal Treasury.

Oil and gas operations

The Branch of Oil and Gas Operations supervises the discovery, development, and production of crude oil and natural gas and associated products from leased public, acquired, Indian, Outer Continental Shelf, and Naval Petroleum Reserve lands.

Supervision includes inspection of operations to insure compliance with lease terms, operating regulations, and approved drilling and production plans. It includes the performance or witnessing of pressure and flow tests on oil and gas wells, the determination of spacing patterns that will permit optimum production with minimum expenditure of reservoir energy, and the investigation of unleased Federal deposits near producing fields to determine whether drainage of oil and gas is threatened. In the event of such drainage, agreements are negotiated to compensate the Government for oil and gas drained, or such lands may be recommended for lease under competitive bidding procedures.

The accompanying table shows the production of crude oil and gas and of other mineral products, the total value of mineral products, and the royalties received from supervised leases on the several categories of Federal and Indian lands during fiscal year 1966.

Mineral production, value, and royalty for fiscal year 1966 [1]

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other [2] (tons)	Value (dollars)	Royalty (dollars)
Public	185, 864, 000	730, 688, 000	468, 445, 000	28, 208, 000	794, 335, 000	82, 848, 000
Acquired	8, 269, 000	26, 170, 000	631, 000	255, 000	33, 811, 000	3, 961, 000
Indian	33, 369, 000	104, 763, 000	79, 693, 000	8, 943, 000	126, 729, 000	16, 007, 000
Military	1, 905, 000	51, 715, 000	60, 681, 000		15, 768, 000	2, 795, 000
Outer Continental Shelf	161, 300, 000	740, 300, 000		1, 408, 000	660, 000, 000	115, 800, 000
Naval Petroleum Reserve No. 2	3, 563, 000	5, 733, 000	11, 884, 000		12, 496, 000	1, 721, 000
Total	394, 270, 000	1, 659, 369, 000	621, 334; 000	38, 814, 000	1, 643, 139, 000	223, 132, C00

[1] Estimated in part.
[2] All minerals except petroleum products; includes coal, potassium, sodium, and so forth.

Mining operations

The Branch of Mining Operations is responsible for supervision of mining operations for coal, potash, sodium, phosphate, and other leasable minerals on Federal and Indian lands. Examinations and investigations are made of the deposits to determine their potential and to verify discoveries under prospecting permits. The Branch recommends lease terms and royalty rates, and approves methods for prospecting and plans for mine development. Supervision includes inspection of operations to verify compliance with such approved methods and plans.

Recent exploration has revealed large deposits of lead and associated minerals in the "new lead belt" in southeast Missouri, much of it on acquired Federal lands. This new lead belt has an estimated potential of about a billion tons of lead ore containing 20 to 30 million tons of recoverable lead and associated minerals such as copper, zinc, silver, and cadmium, as well as separate copper and iron ore bodies. A large portion of these ores underlies National forest land and will return millions of dollars in royalty to the Government.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND PUBLIC HEALTH

Geology and hydrology applied to engineering and public health have assumed a much greater importance in our national life in recent years. In view of the increasing concentration of population in small areas, the planning and development of new structures are dependent upon the appraisal of geologic and hydrologic environments. For example, considerable concern exists on the public safety aspects of locating nuclear-reactor power generators in areas subject to geologic hazards.

This year the Geological Survey undertook on behalf of the Advanced Research Projects Agency (ARPA) of the Department of Defense, technical directorship of two field exercises for the VELA On-Site Inspection Program. The purpose of this program was to appraise the ability of a multidisciplined search team to identify and verify underground nuclear explosions, first in a simulated environment, and second under actual test conditions.

The Geological Survey continues to provide the U.S. Atomic Energy Commission (AEC) with the level of consultation required to evaluate the safety of nuclear-reactor power plants. Similarly, the effects of nuclear explosions, both from underground testing of weapons and for peaceful uses of nuclear energy, on the geologic and hydrologic environment are assessed for the AEC. These studies are preceded by engineering geology and hydrologic investigations designed to facilitate the development of deep drill holes and underground chambers for the emplacement of nuclear explosive devices in areas of complex stratigraphy and structure. Corollary research efforts are conducted on such diverse problems as geologic factors affecting ground motion from explosions, stability of underground openings as deduced by geophysical methods, magnetic properties of volcanic rocks, recent faulting, and disposal of radioactivity by transport of radionuclides, partly in solution and partly absorbed on sediment particles. Investigations also are underway to evaluate geohydrologic methods of disposing of gaseous, liquid, and solid wastes from existing and planned nuclear installations.

Contamination of natural sources of surface and ground water from such agents and causes as pesticides, detergents, coal-mine drainage, municipal and industrial wastes, and chlorides is the subject of a broad area of investigation. The concern for redevelopment of the Appalachia region has focused considerable concern on mine-water drainage and its effects, both on usable water supplies and on further mining development. Control of such effects is dependent upon broader knowledge of the interaction of geologic, hydrologic, geochemical, and biochemical factors in coal-mining areas.

Potential hazards to public health from excessive elements in the environment are being studied in conjunction with other programs and at the request of, or in consultation with, scientists both in and outside of the government. Attempts have been made to relate local concentrations of a wide variety of elements to problem diseases in restricted areas. Natural or induced chemical imbalances occurring locally may be transmitted to humans or animals through the atmosphere, water, vegetation, or soil.

Engineering-geology mapping programs are continuing in 10 urban areas across the country and are being coordinated with earthquake studies of Juneau and Anchorage, Alaska. Relating geologic data to specific needs of land-use planners has become the principal goal of another study of Lexington and Fayette County, Ky. Users of such studies include an ever widening field of specialists now that the value of engineering geologic maps is gaining recognition. Topical engineering geology studies have been similarly accelerated in such diverse fields as the delineation of porosity and cavities in rocks by gravity and seismic methods, the relation of coal-mine bumps to fault displacement, rock-mechanics studies in the field and laboratory, and analysis of rock falls in roadcuts in Massachusetts and from steam explosions at Mount Rainier.

Land subsidence caused by fluid withdrawal in poorly compacted, porous rocks has occurred in a number of built-up areas. Several studies are underway to detail the amount of subsidence, to verify the cause and to evaluate the degree to which compaction may be resulting in changes in the hydrologic properties of an aquifer system.

The need for better knowledge of forces responsible for national catastrophes was again demonstrated in 1965 by two major events: (1) hurricane Betsy, which struck parts of Florida, Louisiana and Arkansas, took 80 lives and caused more than a billion dollars of damage, and (2) floods in the central plains which took 50 lives and caused damage in excess of $350,000,000. Toward this end, the Geological Survey is concentrating considerable effort to measure stream discharge, determine flood frequency, and compile flood-inundation maps. Such information is essential in order that an adequate warning system can be devised and that land use can be more intelligently planned in danger areas.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

SITE EVALUATION

Corral Canyon reactor site

A detailed study of the Corral Canyon reactor site located along the California coast 28 miles west of Los Angeles was carried out by R. F. Yerkes and C. M. Wentworth. The site is located within the Malibu Coast zone, a mile-wide, east-west-trending belt of deformed Miocene sedimentary and volcanic rocks. The Malibu Coast zone contains the north-dipping Malibu Coast fault, which in turn is one of several faults that form the east-west-trending Santa Monica fault system at the south margin of the Transverse Ranges. The Santa Monica fault system is physically connected with the northwest-trending, active Newport-Inglewood fault zone of the western Los Angeles basin. Local and areal structural analysis demonstrated that the structural features of the intensely deformed clayey bedrock of the Corral Canyon site are geometrically and probably genetically related to north-over-south thrusting along the Malibu Coast fault that occurred chiefly between late Miocene and late Pleistocene time. The bedrock at the Corral Canyon site hence was deformed in an active structural environment that, on the basis of information obtained from regional geology and seismology, probably still exists.

Control on the minimum age of deformation that has occurred in the Malibu Coast zone is critical in evaluating the probability of faulting in the near future. By use of radiocarbon dating, uranium-series disequilibrium dating, detailed soil morphology, analysis of time required for translocation of calcium carbonate in the soils, and pollen analysis, it has been demonstrated that the youngest deformation that could be tectonic, and for which clear evidence exists in the Corral Canyon area, occurred after about 180,000 years ago and prior to about 10,000 years ago. It was predicted, therefore, that the probability of faulting within the lifetime of the proposed plant (50 years) is very low.

VELA ON-SITE INSPECTION PROGRAM

The U.S. Geological Survey was responsible for and directed two field exercises for the VELA On-Site Inspection Program during 1965. The exercises were sponsored by the Advanced Research Projects Agency of the U.S. Department of Defense. These exercises were the first ones to be conducted by the United States. The first exercise was held in the Montezuma Creek area east and southeast of Blanding, Utah, during the period September 13–October 3. The second exercise was held on Amchitka Island, Alaska, during the period November 19–December 10, following the LONG SHOT underground nuclear explosion on the island.

The purpose of the VELA On-Site Inspection field exercises was to appraise the ability of a search team to identify and verify the sites of underground nuclear explosions. The field exercise in southeastern Utah, called Project ARKOSE, was the first attempt to assemble the separate search components into an integrated search team and to evaluate team composition, personnel, logistic and support requirements, and efficiency as an operating unit in the field. No actual nuclear test was involved. The second exercise, called Project BRECCIA, was a follow-on to Project ARKOSE and was designed to evaluate the same facets of the On-Site Inspection concept under severe climatic conditions.

The field exercises were largely training and learning exercises for the integrated search team. Participants, in addition to the Geological Survey, included U.S. Naval Radiological Defense Laboratory, Isotopes, Inc., Texas Instruments, Inc., and Stanford Research Institute. Other organizations represented by observers and evaluators were Advanced Research Projects Agency, Arms Control and Disarmament Agency, United Kingdom Geological Survey, and Institute for Defense Analysis. Team activities included flying for acquisition of aerial photography; collecting air, soil gas, and water samples; drilling several shallow holes with a small portable drill rig; and making on-the-ground observations.

The results of these exercises will form part of an appraisal of this Nation's capability to make on-site inspections to detect and identify underground nuclear explosions.

PLOWSHARE PROGRAM

The aim of the PLOWSHARE Program of the U.S. Atomic Energy Commission is to develop means of utilizing nuclear explosions for peaceful purposes. The U.S. Geological Survey contributes to this effort in various ways, including selection of sites potentially useful for experiments, making detailed studies of the geology and hydrology of explosion sites, and making feasibility studies of beneficial applications of nuclear explosions in the field of natural resources.

Nuclear explosions and the recovery of geothermal energy

H. H. Waldron has begun a feasibility study of the application of nuclear explosives to the recovery of geothermal energy. The purpose of the study is to review and evaluate existing information on geothermal areas in the United States to determine their broad geologic and hydrologic setting and to investigate in detail the more promising thermal areas as potential sites for beneficiation by nuclear explosions. Results to date have not been encouraging because it appears that the required detailed knowledge of the subsurface geologic and hydrologic environment is lacking and could only be obtained at prohibitive cost.

Oil-shale fracturing by nuclear explosions

The U.S. Atomic Energy Commission, the U.S. Bureau of Mines, and the U.S. Geological Survey are cooperating in an investigation of potential sites in the Piceance Creek Basin of Colorado for an experiment to use a nuclear explosion to fracture oil shale preparatory to in-situ retorting. The U.S. Bureau of Mines drilled a 2,600-foot-deep exploratory hole in sec. 13, T. 1 N., R. 98 W., in Rio Blanco County, Colo., to determine the geology and hydrology of the oil-shale section. The hole penetrated approximately 35 feet of alluvium, 720 feet of the Evacuation Creek Member of the Green River Formation, and 1,835 feet of the Parachute Creek Member. Continuous core was taken from a depth of 770 feet to the bottom of the hole; J. R. Ege, M. T. Husar, and R. D. Carroll examined the core to determine fracture frequency and used geophysical logs to make preliminary estimates of oil yield of the shale. D. L. Coffin and F. A. Welder have analyzed the hydrologic properties of the rock penetrated by the hole, and their results indicate that the oil shale has several water-bearing zones that might seriously hinder in-situ retorting. In-hole testing is necessary to determine actual water-bearing zones and flow rates; these tests are planned in 1966.

GEOLOGIC AND HYDROLOGIC EFFECTS OF NUCLEAR EXPLOSIONS

Project LONG SHOT

The LONG SHOT event was an underground nuclear explosion detonated October 28, 1965, on Amchitka Island, Alaska.

W. E. Hale, W. A. Beetem, and R. A. Young have studied the surface and ground-water system on the island and have observed the postshot hydrologic effects. The fresh ground-water system in the vicinity of the LONG SHOT site moves mostly through fractures in the volcanic bedrock. Fractures associated with the through-going faults are the most permeable parts of the system. The linear fracture zones divide the natural ground-water circulation system into hydrologically separate blocks. The permeability of the fracture zones is 1–10 gallons per day per square foot, and the effective porosity is of the order of 1 percent. The unfractured bedrock between fracture zones probably has a permeability ranging from 0 to 0.1 gpd/ft^2, and the effective porosity probably is 0.01 percent.

The depth of the fresh-water zone on Amchitka Island at the LONG SHOT site exceeds 2,500 feet. Saline water under the fresh-water system is hydraulically connected with the fresh-water system, mostly through the vertical fracture zones.

Analyses of preshot and postshot samples of water collected from wells, ponds, and streams on the island indicate no significant changes in the chemical quality of the water. The flow of nearby streams was unaffected by the explosion, except for a transitory overspilling of settling ponds into two small streams.

F. A. McKeown and W. P. Williams measured the displacement of the surface of the ground caused by the LONG SHOT explosion. They interpret their data to indicate that the explosion triggered tectonic strain release. The measured permanent ground displacements exceed, by factors of 3 to 8, the theoretical displacements calculated on the basis of spherical expansion of the explosion-produced cavity in a noncompressible rock. If the "excess" displacement occurred along a fault, as seems probable, the strain energy release is of the order of 2.3×10^{19} ergs. This figure compares favorably with the observed greater magnitude of seismic energy recorded at teleseismic distances over that predicted on the basis of assumed yield of the nuclear device. Though the close agreement of these two independent sets of measurements and calculations supports a hypothesis of tectonic strain release, some of the necessary assumptions are so large that a unique answer may never be attained.

Project SALMON

The SALMON event was an underground nuclear explosion in the Tatum salt dome, Lamar County, Miss., October 22, 1964. Shortly after the explosion a number of well owners in the vicinity of Tatum salt dome reported an increase in turbidity and color of the well water, and in some cases a decrease in water yield. R. E. Taylor, who has studied the reports, notes that in most cases the quality of water improved within a few days. Decreases in well yield are attributed to the fall of foreign matter into check valves and to normal deterioration of well systems. No well suffered structural damage as a result of the SALMON event. Screens removed from several wells were found to be in various stages of rust incrustation and corrosion resulting from natural causes prior to the nuclear explosion.

R. E. Taylor and J. W. Lang found that, although the water levels in five artesian aquifers on and adjacent to the Tatum salt dome in Mississippi were affected substantially by the explosion, the event caused no permanent water-level change. A rise of about 56 feet was measured in one well atop the dome, and a few weeks was required before the level returned to preshot stage. Hydrographs for other observation wells showed rises ranging from 0.36 foot to 12 feet, depending on the distance from shotpoint and depth and characteristics of the aquifer. The water level in a cavernous sandy limestone aquifer on the flank of the dome, but not overlying it, declined temporarily at least 2 feet after the detonation. About 5 days was required for the water level to recover to preshot level. No satisfactory explanation for the decline has been found, although aquifer response to earthquakes has resulted in temporary declines in some aquifers. Little or no measurable effect was observed on the water table in the shallow deposits as a result of the explosion.

V. J. Janzer, B. P. Robinson, and S. J. Rucker have compared radiochemical analyses of preshot and postshot water samples collected from numerous wells surrounding the Tatum salt dome. They report no significant changes in radioactivity levels in any of the water samples.

Geologic factors affecting ground motion from explosions

The integrated results of three separate studies are (1) the relation of explosion-produced surface fractures to natural bedrock joints, (2) the relation of explosion-produced fractures to subsurface lithology, and (3) the relation of recorded surface-wave patterns to explosion-produced fractures. These results form a basis for predicting the directions in which the largest surface-wave amplitudes from nuclear explosions will occur. This suggested predictive capability also may have a converse use: that is, explosion sites may be selected to direct surface-wave ground motion in preferred directions. Damage to buildings from explosion-produced ground motion at some locations might, therefore, be minimized by proper selection of explosion sites.

GEOLOGIC AND HYDROLOGIC STUDIES

Ground-water hydrology of the Nevada Test Site

William Thordarson has studied the ground-water system beneath Rainier Mesa, as it is revealed by drill holes and tunnels. He reports that the 600- to 800-foot-thick zeolitic tuff of the Piapi Canyon Group and the Indian Trail Formation under Rainer Mesa controls the recharge rate of ground water to the underlying and more permeable Paleozoic aquifers. The water moves principally through steeply dipping fractures and fault zones. This water is perched by the poor interconnection of the fractures themselves. The top of the zone of fracture saturation is irregular but generally is near the top of the zeolitic tuff at an altitude of about 6,000 feet.

L. R. West and William Thordarson closely studied the geologic and hydrologic data obtained during the deepening of test well E in Yucca Flat. Periodic measurements, made as the well was deepened from 1,875 to 2,620 feet, showed a drop in static water level from 1,716 to 1,780 feet below land surface. This decline in head indicates the ground water in the tuff in Yucca Flat is semiperched with respect to water in the underlying Paleozoic dolomite. The 1,780-foot depth is the piezometric surface in the Paleozoic dolomite aquifer and is 2,391 feet above mean sea level. The water in the tuff is of the sodium bicarbonate type, with low dissolved-solids content and a relatively large silica content. Hardness of the water is 4 parts per million as $CaCO_3$.

Stability of underground openings

J. H. Scott and R. D. Carroll have applied sonic geophysical methods to determine the stability characteristics of rocks around underground openings, such as tunnels and shafts. At the Nevada Test Site, they have demonstrated the presence of a low-velocity zone that surrounds tunnels in tuff and granite. The zone is as much as 10 feet in thickness in both kinds of rock, and develops its maximum thickness very soon after tunnel excavation. The thickness of the low-velocity zone apparently is unrelated to size of the excavated opening, but is generally dependent on the degree of fracturing, being thickest in severely fractured rock.

Magnetic properties of volcanic rocks, Nevada Test Site

G. D. Bath has investigated the magnetic properties of volcanic rocks at the Nevada Test Site and surrounding areas. Laboratory measurements of surface and underground rock samples demonstrate that remanent magnetization is responsible for almost all the prominent aeromagnetic anomalies associated with Tertiary volcanic rocks. Although average induced magnetization ranges from about 1.5×10^{-4} electromagnetic units per cubic centimeter for rhyolitic lava and tuff to 3.6×10^{-4} for trachybasalt, this effect is not sufficient to explain measured anomalies. Remanent intensities range from about 1.5×10^{-4} emu/cc for nonwelded tuff, to about 30×10^{-4} for strongly magnetized welded tuff, to about 85×10^{-4} for a very magnetic facies of rhyolite, and to about 70×10^{-4} for trachybasalt.

Of the more than 50 volcanic units investigated, only 12 have the remanent intensity and thickness required to produce aeromagnetic anomalies. Of the 12, 6 are normally magnetized and produce positive anomalies and 6 are reversely magnetized and produce negative anomalies. The remanent direction in rock free from near-surface lightning effects is consistent within individual stratigraphic units, and is either approximately along (normal polarity) or opposite (reversed polarity) to the present geomagnetic field.

The thick welded tuffs of the Fraction Tuff and tuff of White Blotch Spring, north of the Nevada Test Site, are reversely magnetized and produce distinctive negative aeromagnetic anomalies. The anomalies parallel the general trend of the Kawich and Reveille ranges and indicate that these volcanic units are present in down-faulted blocks in basin areas as well as in mountainous areas of surface exposures.

The aeromagnetic method offers a rapid reconnaissance method of investigating areas of Tertiary volcanic rock for the presence of thick reversely magnetized welded tuff units. The effects of these units are readily discernible in magnetic data and thus provide a basis for regional geologic mapping.

Engineering geology and hydrology of Pahute Mesa, Nevada Test Site

For the past several years the U.S. Geological Survey has provided geologic and hydrologic advice to the U.S. Atomic Energy Commission in the development of deep drill holes and underground chambers beneath Pahute Mesa. The most consistently low-water-yielding rock types on Pahute Mesa are zeolitized ash-fall and ash-flow tuffs. Chambers mined in these rock types below the water table have yielded only minor amounts of water. Fractures and faults are common in the tuffs, but their permeability is low.

Rhyolitic lava flows and densely welded tuffs commonly have open fractures and well-developed secondary permeability. For this reason the rhyolitic flows and welded tuffs are not suitable for mined cavities below the water table.

Because of the importance of geologic structure and stratigraphy to the mining of underground chambers and to the ability to drill large-diameter holes, it has been necessary to thoroughly explore the subsurface of Pahute Mesa. A late Miocene caldera has been delineated beneath eastern Pahute Mesa. It is named the Silent Canyon caldera; it is elliptical in plan and measures 10–14 miles across. Except on its east edge, the caldera is completely obscured by younger volcanic rock, including ash-flow sheets from several other caldera centers.

DISPOSAL OF RADIOACTIVE WASTES

Research related to the disposal of radioactive wastes in fiscal year 1966 included: (1) studies of the transport of radionuclides discharged into surface streams; (2) studies of the transport and distribution of radionuclides discharged into earth materials; and (3) studies of existing and planned nuclear installations, to evaluate methods of disposing of gaseous, liquid, and solid wastes, and to appraise geohydrologic aspects of disposal methods. Most of the work was done in cooperation with the U.S. Atomic Energy Commission.

TRANSPORT OF RADIONUCLIDES IN SURFACE STREAMS

Radionuclides in the Columbia River

When water used to cool nuclear reactors upstream from Richland, Wash., is returned to the Columbia River it contains small amounts of radionuclides which are transported toward the ocean, partly in solution and partly sorbed on suspended particles. W. H. Haushild, H. H. Stevens, Jr., G. R. Dempster, Jr., and J. L. Glenn, of the U.S. Geological Survey, and R. W. Perkins, of Battelle Memorial Institute, report that the sediments in the Columbia River between Pasco, Wash., and Astoria, Oreg., are potentially high sorbers of radioactive ions. Exchange capacities (in milliequivalents per 100 grams) range from 2.6 to 11 for sand-size particles; from 5.9 to 41 for silt; and from 44 to 79 for clay. The combined exchange capacities of silt and clay constitute 90 to 95 percent of the total exchange capacity. The total exchange capacity per unit of sediments decreases downstream from Pasco to Vancouver, Wash., but the sorption potential increases in the downstream direction because both sediment load and the percentage of rock fragments that have high exchange potential increase downstream.

Radioactive tracers were introduced into the Columbia River in cooling water from the reactors at Hanford, Wash., to measure flow times from Pasco, Wash., as far downstream as Astoria, Oreg. J. L. Nelson and R. W. Perkins, of Battelle Memorial Institute, and W. L. Haushild, of the Geological Survey, (J. L. Nelson and others, r2067) found that flow times determined from the decay of Na^{24} (15-hour half life), released steadily, agreed closely with flow times determined from arivals of peak concentration of instantaneously released I^{131} (8-day half life). Flow times for the 224 river miles from Pasco to Vancouver, Wash., ranged from 14.6 to 3.6 days (range in discharge at Vancouver, 108,000 to 630,000 cubic feet per second). The graphic relation of flow time to discharge was plotted from the results of four tests at different discharges, for use in estimating flow times at all discharges, at several locations between Pasco and Vancouver. The data also furnish a limited description of the dispersion characteristics of I^{131} in the Columbia River.

Radionuclides in sediments in the Columbia River estuary

Small portable equipment for obtaining cores from sandy bottoms that underlie rapidly flowing water has not been available until recently. E. A. Prych and D. W. Hubbell (r2068) describe a portable sampler developed for use from a boat to investigate the radionuclides in bottom sediments of the Columbia River estuary in Oregon and Washington. Six-foot-long cores were collected throughout the estuary for analyses of the concentration and vertical distribution of radionuclides, to complement radioactivity measurements made with a sled-mounted, underwater, radiation-detection system. The data analyzed indicate that silt, clay, and organic matter sorb the greatest amounts of radionuclides per unit weight, but that the bed of the estuary is mainly sand. In areas where fine sediment and organic material accumulate, the radiation intensity is as much as 20 times greater than the average intensity in sand.

Principles of stream-transport phenomena

Radionuclides which leave solution in stream water to become adsorbed on sediment particles are transported or deposited along with stream sediments. To understand the behavior of radionuclides in waste water discharged to streams, it is therefore necessary to understand both the physical and chemical properties of the stream sediments and the hydraulic mechanisms that control sediment transport.

V. C. Kennedy has sampled the sediment load of 21 streams in the conterminous United States in order to characterize the mineralogy and cation-exchange capacity of their suspended and bed materials under different flow conditions. The study shows that the cation-exchange capacity of clay-size sediment from streams in the eastern part of the United States is lower than that in the west-central and western parts of the country. Kennedy also finds that cations absorbed on sediment exert a strong influence on the chemical composition of stream water. Thus, the ratio of cations absorbed to cations in solution is highest in western streams, which have the highest concentrations of suspended sediment.

The hydraulic behavior of bed-material sediments has been investigated by W. W. Sayre and D. W. Hubbell, using a radiotracer technique in which sand grains labeled with radioactive Ir^{192} were introduced into the North Loup River, Nebr. and monitored with a sled-mounted scintillation detector. Sayre and Hubbell developed a mathematical model, based on probability theory, to characterize the dispersion process. Observed and theoretical distributions agree well except near the point of injection into the stream, in the downstream region, of very low tracer concentration. They point out, however, that until the relations between hydraulic and sediment parameters and the constants in the theoretical distribution function are defined, the constants can be evaluated only by experiment.

TRANSPORT AND DISTRIBUTION OF RADIONUCLIDES IN EARTH MATERIALS

Disposal of waste waters in alluvium, Los Alamos, N. Mex.

Treated liquid waste water having a low level of radioactivity is released into alluvial sediment in a canyon at the Los Alamos Scientific Laboratory, N. Mex. W. D. Purtymun and E. C. John, with G. L. Johnson of Los Alamos Scientific Laboratory (p. D250–D252), report that the clay and silt fraction, composed mainly of montmorillonite and illite clays, has the greater affinity for radionuclides, but that the sand and granule fraction retains most of the radionuclides because the coarse material is much more abundant. Nearly all the radioactive strontium is retained in the upper 1 foot of the alluvium, and 70 to 99 percent of the other radioactive elements is retained in the upper 3 feet. Radioactivity decreases with distance downstream from the point of release at the treatment plant. Buildup of radioactivity does not occur at the point of release because the sorbed radionuclides are dispersed as the alluvial particles are flushed downstream by intermittent streamflow and redeposited in the canyon.

STUDIES AT NUCLEAR-ENERGY FACILITIES

Hydrology of radioactive-waste disposal, National Reactor Testing Station, Idaho

Radioactive waste waters from the chemical reprocessing of nuclear fuels and from test-reactor operation at the National Reactor Testing Station (NRTS) are discharged to the ground through a deep well and through seepage pits. J. T. Barraclough reports that, of the several radionuclides that are present in the waste at the discharge points, only tritium is detectable at significant distances from the disposal sites. The tritium concentration of water in wells on the NRTS, downgradient from disposal sites, has decreased in the past year. So far, no satisfactory explanation of the decrease has been found.

Exploration of bedrock at Savannah River Plant, S.C.

I. W. Marine (r0310) reports the use of radioactive iodine as an inhole tracer, in packed-off intervals of deep drill holes at the Savannah River Plant near Aiken, S.C., to locate zones of water-transmitting fractures in the metamorphic basement rocks. The interconnection and water-conducting properties of some fractures were determined by pumping water from packed-off sections of one hole while making tracer tests in another.

WATER-CONTAMINATION STUDIES

The development of water resources is restricted or complicated in many areas by the presence of undesirable waste products and natural constituents in surface and ground waters. The contaminants include pesticides, detergents, coal-mine drainage, municipal and industrial wastes, and chlorides.

PESTICIDES AND DETERGENTS IN WATER

National pesticide network

A national pesticide monitoring network was instituted in October 1965, with the establishment of 11 sampling stations in the Western States. Analyses by Eugene Brown and Y. A. Nishioka of monthly samples collected during the winter of 1965–66 revealed no reportable quantities of pesticides. In the areas covered, however, the winter period is normally characterized by high streamflow and low irrigation demands, and it is therefore the season when leaching of the soil is likely to be the least.

Pesticides in the Boise River basin, Idaho

Eugene Brown and Y. A. Nishioka also carried out limited reconnaissance sampling in the Boise River basin, Idaho, during the summer of 1965. Their survey indicated the presence of chlorinated hydrocarbons. As much as 1,200 parts per trillion of Dieldrin and 600 ppt of Lindane were found near the mouth of the Boise River at Notus, but no herbicides were detected.

Pesticide study in Utah

A. H. Handy and G. W. Sandberg report that the pesticides Dieldrin and Heptachlor do not reach the shallow ground-water aquifers near Milford, Utah, even though these pesticides have been used to control weevils and cutworms in this area for at least 5 years. Recent literature suggests that the pesticides may have been temporarily or permanently arrested in the soil or in alluvium above the water table.

Persistence of pesticides in North Park, Colo.

The persistence, decomposition rate, weathering, and lateral and vertical migration through the soil of the iso-octyl ester of 2, 4 Dichlorophenoxy acetic acid (2, 4–D) were investigated in North Park, Colo., by P. J. Burcar, R. L. Wershaw, M. C. Goldberg, and Lloyd Kahn. Rapid breakdown of the iso-octyl ester was observed, and at the end of 2 weeks no iso-octyl ester was in the soil. However, the free acid 2, 4–D could be detected up to 6 weeks after spraying. Downward migration occurred, but most of the acid remained in the top inch of the soil profile. No lateral migration of the acid was observed.

Detergents in ground water on Long Island

On the basis of monthly sampling from 1961 to mid-1965, N. M. Perlmutter and A. A. Guerrera report variations in ABS (alkylbenzenesulfonate) concentrations in the ground water at three well fields in Suffolk County, N.Y. Concentrations ranged from less than 0.02 to about 5 parts per million in a water-table aquifer of Pleistocene age. Most of the variations seem to correlate with seasonal changes in pumping at the well fields and with natural fluctuations of the water table. A trend toward increased concentration is evident in parts of the shallow aquifer, and at one well field intermittent traces of ABS have been detected in an underlying confined aquifer of Cretaceous age. No ABS contamination has been observed in water from deep supply wells.

ACID MINE WATER

Coal-mine drainage in Appalachia

A stream-quality investigation of Appalachia in May 1965 disclosed that deterioration of water quality due to coal-mine drainage is particularly severe in Pennsylvania, West Virginia, and Ohio. Fewer streams in southern Appalachia were influenced by mine drainage. High sulfate content, free mineral acid, and low pH are typical of most of the affected streams. The chemical quality of the water at nearly 200 of the 318 sites visited did not meet recommended drinking-water standards, according to J. E. Biesecker and J. R. George.

Coal-mine drainage in Schuylkill River basin, Pennsylvania

J. E. Biesecker, J. B. Lescinsky, and C. R. Wood have found that underground mining in the anthracite coal region within the Schuylkill River basin has a much greater influence on stream quality than strip mining, despite the fact that, in recent years, underground mining has accounted for only about 40 percent of total coal production in the basin. About 33 percent of the water and 66 percent of the solute load in major tributaries is discharged from underground mines, while only 1 percent of the water and half a percent of the solute load is discharged directly from strip mines.

Acid mine drainage in Cane Branch, Ky.

R. J. Pickering and J. J. Musser report that the acidity and the content of dissolved solids of Cane Branch, in McCreary County in southern Kentucky, continued to decline during the period 1962–64. Highly mineralized acid water has been produced by the weathering of iron sulfide minerals exposed during coal strip mining in the Cane Branch basin in 1956 and 1959. In spite of their continuing decline, the acidity and dissolved-solids content of water in Cane Branch remain much greater than that of streams unaffected by mining.

Basic knowledge needed for control of acid mine drainage

Gerald Meyer, G. L. Chute, G. H. Wood, Jr., and W. T. Stuart have critically examined the results of efforts to control polluting effluents from underground coal mines. They conclude that inadequacy of our knowledge of geologic, hydrologic, geochemical, and biochemical phenomena in the underground environment in and near the mines is the chief reason for lack of success in this effort. The polluting effluents cannot be effectively controlled until the chemical and other processes which control the generation of the pollutants are better understood.

MUNICIPAL AND INDUSTRIAL WASTE

Dispersion of waste in Metedeconk River estuary, New Jersey

Municipal wastes released to the Metedeconk River in New Jersey are suspected of contributing to fish kills in the river estuary by consuming large amounts of dissolved oxygen. To simulate the movement and dispersion of soluble wastes in the 3-mile tidal portion of the estuary, G. M. Horwitz injected and traced rhodamine BA dye. The dye dispersed throughout the estuary within 1 day. The peak dye concentration traversed the estuary in about 3 days. Tidal action diluted the dye to below measurable quantities within 15 days.

Wastes in Yellow Creek, Ky.

The quality of water in Yellow Creek near Middlesboro, Ky., shows the combined effects of coal-mine drainage and the disposal of industrial wastes into tributaries of the creek, according to R. J. Pickering. During low streamflow, the solute content commonly exceeds 500 parts per million. Coal-mine drainage causes very hard water and contributes sulfate ions to the stream, and during prolonged periods industrial wastes keep the turbidity high and the content of dissolved oxygen low. Fern Lake, the source of water for Middlesboro, is not influenced by contaminants, and throughout the year it provides water of good quality, with a solute content of less than 30 ppm.

Fluoride and phosphate contamination in Florida

Phosphate-processing plants contributed 4 to 100 tons per day of fluoride wastes to the Alafia River during 1965, and from ½ to 10 tons per day to the Peace River, according to L. G. Toler. Accompanying phosphate wastes were generally 2 to 10 times greater than the fluoride. Study of 200 analyses of fluoride in samples of water from wells indicates that ground water in the area generally has not been contaminated by the industry.

CHLORIDE-CONTAMINATION STUDIES

Chloride in ground water at Camden, N.J.

Increased concentrations of chloride, observed in the ground water at Camden, N.J., during the fall of 1965, are attributed by Ellis Donsky to the persistence of drought conditions. Salt and brackish water penetrated upstream in the tidal reach of the Delaware River during periods of low streamflow. The salt front in the river (with chloride of 250 parts per million) reached the Camden area at the end of October, and by December chloride concentrations of up to 60 ppm were noted in some wells. The normal range of chloride in the ground water in the fall is 18 to 35 ppm.

Ground-water contamination by road salt

Investigations by S. J. Pollock indicate that shallow ground water near seven major highways in eastern Massachusetts has been contaminated by the winter salting of highways. The highways have been in use for periods ranging from 1 to 20 years. At all sampling sites, ground water contained chloride concentrations greater than that (15 parts per million) prevalent in the area. The highest chloride content observed was 140 ppm, except for 2 sites near salt-storage piles where the content reached several thousand parts per million.

Natural brine in the South Fork Ninnescah River basin, Kansas

A. M. Diaz reports that seeps and springs between Cairo and Cunningham, in south-central Kansas, are major sources of brines discharged to the South Fork Ninnescah River. These natural brines consist predominantly of sodium and chlorine ions, with significant amounts of calcium, magnesium, and sulfate.

When the streamflow of the South Fork Ninnescah River at Murdock is 100 cubic feet per second, the solute load is 220 tons per day, of which 70 percent is sodium chloride. At this rate of discharge, about 90 percent of the solute load is contributed by the inflow of natural brine upstream from Cunningham.

Some minor brine pollution in the South Fork Ninnescah River results from the leaching of residual salts remaining from past oil-field activity. Some brine pollution also may result from present oil-field activity; however, most of the brine now produced is pumped into deep disposal wells, and it is therefore believed not to affect the local surface and ground water supplies significantly.

Salt-water encroachment in Florida

Salt-water intrusion continues to be a threat in southeastern Florida as water demands increase, according to C. B. Sherwood, F. A. Kohout, and Howard Klein. Although the salt front generally has stabilized in conformance with the ground-water levels maintained by the regional water-control system, problem areas continue to occur because of changes in canal systems, increased pumpage, operation of salinity controls, and occasional topping of the land surface by storm tides.

Salinity studies in Palm Beach, Broward, and Dade Counties and in the Everglades National Park have disclosed three major problem areas: (1) a major Ft. Lauderdale well field, where salt water has contaminated several wells as a result of uncontrolled drainage and increased pumping; (2) the Miami Springs well field of the City of Miami, where greatly increased supplies (80 to 100 million gallons per day) are being developed by induced infiltration from an inadequately controlled canal system; and (3) a new canal system at the southeastern tip of Florida, which extends inland to an area where water levels periodically decline below sea level, so that salt-water contamination is favored.

DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH

The distribution of elements in rocks, soils, and water is receiving increasing attention from investigators concerned with the relations between environment and public health. During 1966, U.S. Geological Survey scientists studied a wide range of these environmental problems, of which the following paragraphs provide examples. In addition the Geological Survey provided analytical data on trace elements in soils, waters, and plants for use in studies by other government agencies, and by individual scientists working in the fields of medicine and public health.

Chemistry of water supplies in Maryland and New Mexico

H. L. Cannon made a study of available analyses of domestic water supplies in Washington County, Md., (an area of high incidence of cancer) as compared with those from San Juan County, N. Mex., (an area of low incidence). Water samples from New Mexico contain several times more calcium, magnesium, sulfate, sodium plus potassium, and chlorine than samples collected in Maryland. The Maryland domestic waters contain more zinc and nitrate than those in New Mexico.

Abundance and distribution of elements in soils and plants of Georgia

H. T. Shacklette continued a study of the abundance and distribution of elements in soils and plants in Georgia in accordance with a sampling plan devised by personnel of the Heart Disease Control Program, U.S. Public Health Service. A prior reconnaissance sampling program indicated that the abundance of certain elements is regionally controlled, which suggested to personnel of the Public Health Service that there may be a correlation of this element abundance with known patterns of cardiovascular mortality rates in Georgia. The more rigorously controlled sampling program, completed in 1965, included samples of food plants and cultivated soils, in addition to native vegetation and uncultivated soils.

Minor-element contaminants in surface-water supplies

Robert Scott has been concerned with deleterious effects of uranium mining on surface-water supplies in the West. Uranium mining operations in the Shirley basin, Wyoming, have required the discharge of large volumes of water with high concentrations of uranium and radium to the Little Medicine Bow River. This effluent from the subsurface dewatering operations has been run into intermediate settling ponds which have been responsible for the deaths of migratory wildfowl. Overflow from these ponds is tributary to the Little Medicine Bow River, and the high level of radioelements in the river has forced the State to discontinue stocking the stream with fish.

In several Western States, milling spoil piles and drainage of mine water from both active and abandoned mining operations are contributing detectable amounts of radioelements to streams and rivers. The fate and length of residency of radioelements in man's environment must be fully appraised before adequate evaluation of their impact on man can be made.

A report by S. G. Heidel and W. W. Frenier (r0783) has been published in cooperation with the Maryland Geological Survey on the chemical quality of water and trace elements in the Patuxent River basin. The concentrations of manganese, boron, and rubidium are substantially higher, and those of chromium, copper, lithium, nickel, and strontium are lower, in the Patuxent River than in the major rivers of North America.

The geochemistry of natural salt licks

M. R. Mudge and Richard Knight have reported on the geology, chemistry, and biology of some natural salt licks in the Sun River Range, Mont. Three licks frequently used by ruminants in the Sun River area have been developed along outcrops of marine mudstones. Sodium carbonate, sodium sulfate, and also barium and lithium occur in the rocks at the licks in greater quantity than in similar rocks elsewhere. There is less magnesium and strontium in the rocks at the licks.

Lead pollution in Alaskan ice fog

Robert Chapman has cooperated with Carl Benson of the University of Alaska in a study of air pollution associated with ice fog. Benson calculates that the lead concentration in the atmosphere of downtown Fairbanks during periods of ice fog is easily twice that of Los Angeles. Soil samples have been collected by Chapman and analyzed for lead. Higher values have been obtained in urban than in rural areas.

PROBLEMS IN ENGINEERING GEOLOGY AND HYDROLOGY

URBAN STUDIES

Engineering geology map of the city of Lexington and of Fayette County, Ky.

Knowledge of the physical environment is a basic requirement for master planning by agencies commissioned to provide guidance for the orderly growth of a community or region. Ways in which pertinent geologic knowledge can be better imparted to planning commissions and associated engineers is being investigated by a new project of the U.S. Geological Survey. The initial phase of this research has been a study by C. G. Johnson of the application of geology to land-use planning for the City-County Planning Commission of the city of Lexington and of Fayette County, Ky. The study was based on existing standard 7½-minute geologic maps of the county, which were prepared by the Geological Survey in cooperation with the Kentucky Geological Survey. It was found that the needs of the Planning Commission could best be met by the preparation of an engineering-geology map on which geologic map units were grouped into units having similar engineering properties. This map then provided a basis for further interpretation and evaluation of geologic materials for such specific land uses as the construction of houses with and without basements, underground utilities, and water impoundment. A short report accompanying the map furnishes additional information on the geology and explains how the engineering-geology map can be integrated with an existing soils report.

TOPICAL STUDIES

Geophysical study of the Anchor Reservoir area, Wyoming

A precision gravity survey by G. P. Eaton of half a square mile of the floor of Anchor Reservoir in Wyoming has revealed nine negative anomalies similar in configuration to those associated with areas of active subsidence and known leakage elsewhere in the reservoir.[16] Reservoir leakage at the sites of the newly observed gravity anomalies has not yet been confirmed.

[16] U.S. Geological Survey, 1964, Geological Survey Research 1964, Chapter A: U.S. Geol. Survey Prof. Paper 501–A, p. A63.

The survey found that the anomaly associated with the largest and most active sink on the reservoir floor is one order of magnitude greater than any other on the reservoir floor. Detailed analysis of the anomalies indicates that they reflect tabular, vertical zones of low bulk density; several anomalies are elongate in a direction parallel to the trend of the major joints in the local bedrock. It is suggested that the anomalies are caused by zones of high fracture porosity or brecciation associated with joints.

A small negative anomaly outlined by the gravity survey was further investigated by J. S. Watkins, of the U.S. Geological Survey, on behalf of the U.S. Bureau of Reclamation. Watkins applied recently developed seismic-detection methods to infer the location of an underground cave beneath the reservoir area behind Anchor Dam, Wyo., along this gravity anomaly. The seismic method uses sensitive seismometers to detect large-amplitude vibrations set up in underground-cavity walls by small surface explosions. Preliminary evaluation of seismic data indicates that at least one large air-filled cave is present at shallow depth; it may be part of a major subsurface drainage system into which the reservoir leaked.

Relation of coal-mine bumps to fault displacement, Utah

Many large-amplitude earth tremors (magnitude 2.5 to 3.5) that occurred in the Sunnyside coal-mining district of east-central Utah in November 1964 and the spring of 1965 originated along the projected trend of a major, northwest-trending, normal fault. This fault is known only from studies of drill logs and from geophysical investigations. According to F. W. Osterwald and C. R. Dunrud, there seems to have been intermittent movement along the fault since early Paleozoic time, and vertical displacement appears to be progressively greater in older rocks. Drill logs suggest 4,000 to 5,000 feet of displacement in rocks of pre-Permian age, but seismic-refraction records indicate only 2,000–3,000 feet of displacement in Lower Permian carbonate rocks. Surface mapping revealed an associated northwest-trending shear zone, 150 to 200 feet wide, along which Upper Cretaceous rocks are displaced about 65 feet vertically. Energy released by movement along the lower part of the fault apparently triggers movement along secondary faults at higher stratigraphic levels. This, in turn, releases energy that may cause dangerous bumps in nearby coal mines.

Seismic-refraction measurements at Sunnyside, Utah, by B. L. Tibbetts, C. R. Dunrud, and F. W. Osterwald (p. D132–D137) have permitted thickness measurements of part of the stratigraphic section to be made here. In general the section above the upper Paleozoic carbonate refractor horizon ranges from 1.2 kilometers in Clark Valley to 3.7 km in Range Creek.

Rock-mechanics studies in the field and laboratory

Seismic-velocity measurements in the pilot bore of the Straight Creek Highway Tunnel, Colo., by R. D. Carroll and J. H. Scott (p. D138–D143) have successfully outlined zones of fractured and weakened rock in the walls and roof of the bore, which must be considered in designing a tunnel-support system.

R. D. Carroll, J. H. Scott, and D. R. Cunningham (p. C25–C28) have determined the elastic moduli of granitic rocks in two tunnels in Colorado and Nevada from in situ measurements of seismic velocity. Inhole recording with near-surface detonation, and surface recording with near-surface detonation were used in this study. Neither method yielded consistent shear-wave generation, a result attributed to conditions around the energy source and in the transmission path.

Compressional testing of cores of Silver Plume Granite from Colorado by F. T. Lee and T. C. Nichols, Jr. (p. C29–C33), and Nichols and Lee (p. C34–C38), resulted in the formation of slickensides and gouge that resemble features produced in the granite by tectonic deformation. In the laboratory, however, gouge and slickensides are thought to have formed by compressive stress, rather than by movement along large-scale fractures. During compression, lateral bulging of the test specimens prior to complete failure was accompanied by small energy-producing events that probably were caused by dislocation of grains and by shear and tensile fractures produced on a very small scale. The authors conclude that the assumption is not necessarily true that all wide gouge-bearing shattered zones in granite are reliable indicators of displacement along faults, or that gouge and slickensides are formed only by grinding along fault surfaces.

C. H. Roach and D. A. Baldwin have found that some rocks at the immediate ground surface have residual, or conserved, strain that can be determined by measuring the change in resistance of SR-4 electric strain gages as the rock is overcored. They have also found that the amount of residual strain in some rocks can be permanently modified by a small explosively generated stress, and at distances significantly beyond the zone of plastic deformation. These findings indicate that strain-gage techniques might be useful in studying stress or tectonic history, and also suggest that residual strain in rock bodies might be easily relieved by explosive techniques.

Highway engineering studies

Examination by C. R. Tuttle of a rockfall along U.S. Highway 20 in Woronoco, Mass., showed that 1,200 feet of remedial rock-slope excavation is necessary in order to make this segment of roadway safer for travel. The existing rock slope, which is inclined at about 1/4 to 1, consists of schist broken by numerous open joints and foliation planes, many of which dip toward the roadway. Ice wedging and gravity, rather than physical disintegration, are the main factors producing the rockfalls. Neither weathering nor continued rockfall will form a stable slope during the useful life of the roadway. Original plans included remedial excavation for a 2,400-foot segment of roadway, but an estimated 30 percent could be saved by relocating half of the segment.

Twelve comparison surveys have been made this year in Massachusetts by C. R. Tuttle, as part of a research program on the use and improvement of shallow-refraction seismic methods. Bedrock depths and configurations predicted by seismic study at highway construction sites were compared with those later exposed by excavation. Seven sites have only one layer of soil overlying bedrock; the average accuracy of predicted versus actual geologic conditions was 70 percent. Two sites have two layers of soil overlying bedrock, and the accuracy of seismic predictions ranged from 85 to 90 percent. No bedrock was encountered at the remaining three sites, as correctly predicted by the seismic data. Except for the last 3 sites the total number of lineal feet of bedrock surveyed ranged from 42 to 90 percent of the total seismic traverses measured. The 12 comparisons show quantitatively the range of results to be expected from application of the shallow-refraction method. Poor correspondence between predicted and actual conditions is due primarily to such local structural defects as closely spaced and weathered joints, or to highly irregular bedrock topography.

LAND SUBSIDENCE

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

Studies of land subsidence caused by decline in artesian head are continuing in California, Nevada, Arizona, and Texas. These studies are contributing to knowledge of the mechanical and hydraulic properties of compressible aquifer systems, the storage characteristics of semipervious interbeds and confining beds, and the change in the coefficient of storage with time and with change in effective stress.

Subsidence and tilting south of Bakersfield, Calif.

Analysis by B. E. Lofgren of releveling by the U.S. Coast and Geodetic Survey in 1965 indicates continuing subsidence in the Arvin-Maricopa area at the south end of the San Joaquin Valley. Maximum subsidence from January 1962 to March 1965 was 1.58 feet. At the Lakeview compaction-recorded site near the center of maximum subsidence, subsidence averaged 0.44 foot per year in the 3 years and is accounted for by compaction of deposits above a depth of 1,500 feet. The effect of pumping new deep wells has increased the compaction rate in deposits between depths of 800 and 1,500 feet, but the compaction rate in shallower deposits has diminished, with the result that the annual rate of subsidence has remained relatively constant for about 8 years at this site.

Analysis by Lofgren (p. B6–B11) of leveling data obtained in 1953 and 1962 indicates that tectonic movement is occurring in the mountains south of the San Joaquin Valley. (See section "Pacific Coast Region" under "Regional Geology.")

According to F. S. Riley, a recording liquid-level tiltmeter installed on the floor of the San Joaquin Valley near Wheeler Ridge, 24 miles south of Bakersfield, indicated a northwestward tilt of 46 microradians from June to September 1965. The interval of rapid tilting coincided approximately with the period of maximum ground-water pumping, and the effect is tentatively attributed to differential compaction of the confined aquifer system due to reduction of artesian pressures.

Subsidence in Santa Clara Valley, Calif.

The latest complete releveling of the subsidence network of bench marks in the Santa Clara Valley by the U.S. Coast and Geodetic Survey was in the autumn of 1960. However, individual lines were releveled by that agency in February 1963 and April 1965. Analysis of this releveling by J. F. Poland indicates that subsidence has been continuing locally since 1960, at a more rapid rate than from 1954 to 1960. For example, at bench mark J111 Reset, near Sunnyvale, the subsidence rate in feet per year was 0.26 in 1954–60, 0.35 in 1960–63, and 0.31 in 1963–65. Accelerated decline of artesian head during several years of low rainfall since 1960 has caused the increase in subsidence rate.

Physical and hydrologic properties of sediments in subsiding areas in central California

A. I. Johnson, R. P. Moston, and D. A. Morris[17] have made laboratory tests of physical and hydrologic properties of cored samples of sediments in subsiding areas in the San Joaquin and Santa Clara Valleys, Calif. Methods of analysis are described, laboratory results for 549 samples tested are tabulated and discussed, and the relationships between some of the properties are illustrated. The report also includes summary results of consolidation and associated tests made by the Earth Laboratory of the U.S. Bureau of Reclamation on 107 cored samples from the 8 core holes.

Petrology of sediments in subsiding areas in central California

R. H. Meade[18] has studied the petrologic characteristics that influence the compaction of fresh-water-bearing sediments in subsiding areas in the San Joaquin and Santa Clara Valleys, Calif. Emphasis in the report is on the particle-size characteristics and the clay-mineral assemblages, as determined from laboratory studies of cored sediments. He finds that montmorillonite comprises 60 to 80 percent of the clay-mineral assemblage in nearly all the sediments, regardless of source terrane or environment of deposition. Clays rich in montmorillonite are more porous and more compressible under a given change of effective stress than clays that consist mainly of the other clay minerals. He also reports that calcium is the principal exchangeable cation adsorbed by the clay minerals, but that the proportion of adsorbed sodium increases with increasing depth. Montmorillonite with adsorbed sodium as its exchangeable cation is more porous and compressible under a given load than montmorillonite whose exchange positions are saturated with calcium.

[17] A. I. Johnson, R. P. Moston, and D. A. Morris, in press, Physical and hydrologic properties of sediments from subsiding areas in central California: U.S. Geol. Survey Prof. Paper 497–A.

[18] R. H. Meade, in press, Petrology of sediments underlying areas of land subsidence in central California: U.S. Geol. Survey Prof. Paper 497–C.

Compaction of aquifer measured at Clear Lake, Tex.

R. K. Gabrysch reports that the compaction recorder in a well 760 feet deep at the NASA Manned Spacecraft Center at Clear Lake, Tex., recorded compaction of 0.11 foot from March 1964 to March 1965, and 0.11 foot from March 1965 to March 1966. The average rate of land subsidence, estimated from leveling to nearby bench marks in 1959 and 1964 by the U.S. Coast and Geodetic Survey, is about 0.1 foot per year. This would indicate that all of the subsidence is accounted for by compaction of deposits to the depth of 760 feet.

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 1965–66, flood frequency, and flood mapping.

OUTSTANDING FLOODS OF 1965–66

Floods of April 1965 in upper Mississippi River basin

The upper Mississippi River basin was in flood the entire month of April 1965. The flood period extended into May in parts of the basin. Estimation of flood damage in Minnesota ranged from $80 to $100 million, and 59 counties were designated disaster areas. The flood was the greatest since at least 1828 along the eastern Iowa border; stages exceeded previous maxima by 4 to 5 feet. The Mississippi River was above flood stage at Hannibal, Mo., where there are no levees, during the entire month of April. The cause of the flood was prolonged and, at times, intense rain that occurred during the rapid melting of deep snow on frozen ground. Flood warnings prevented loss of lives despite the great magnitude and large areal extent of the flood.

South Platte and Arkansas River floods of June 1965

Record-breaking floods in the South Platte and Arkansas River basins in Colorado and Kansas during the period June 13–19 took 16 lives and caused property damage estimated at more than $200 million. The Denver, Colo., area sustained heavy damage from the South Platte River on June 16. Storms the following day hit the headwaters of Bijou and Kiowa Creeks, tributaries of the South Platte, producing peaks that damaged or destroyed practically all bridges in the area.

All runoff in the Arkansas River basin above John Martin Dam was completely controlled by the reservoir, which was empty on June 1. Heavy rains between the dam and the Colorado–Kansas State line caused outstanding floods on tributaries of the Arkansas River, and Lamar, Colo., only 20 miles downstream from the dam, had one of the worst floods in its history. The Arkansas River flood extended downstream into Kansas, where it was the greatest flood of record on the upper Arkansas River; 3 lives were lost, and flood damage was estimated at $25 million. In Kansas, 24 counties were declared disaster areas.

Flood of June 11, 1965, at Sanderson, Tex.

On June 11, 1965, as much as 8 inches of rain fell in 2 hours near Sanderson, in southwest Texas, causing extremely high peaks on Sanderson Creek and Three Mile Draw. A flood swept through Sanderson, causing several million dollars damage and a loss of 22 lives.

Record-breaking floods in Missouri, July 1965

Torrential rains in Missouri on July 18–19, 1965, covering a narrow belt from Rockport in the northwest to the Blackwater River basin in the west-central part of Missouri caused floods that were the maximum of record along the lower Platte, Little Platte, Fishing, and Crooked Rivers. Maximum rainfall reported was 21 inches at Rockport in 36 hours. The death toll was 9, and damage was estimated at $30 million, of which $25 million was in Platte County.

Hurricane Betsy, September 1965

Hurricane Betsy crossed the southern tip of Florida on September 8, 1965, causing some wind, tide, and flood damage. On September 9, the storm struck the Louisiana coast with full hurricane force. Coastal areas suffered heavy damage, and low areas of New Orleans were flooded by high tides. Eighty lives were lost, and property damage exceeded a billion dollars. The storm extended into Arkansas, where high winds and rain (as much as 5.7 inches) on September 10–12 caused local flooding and damage to cotton, soy beans, and rice in the eastern half of the State.

FLOOD FREQUENCY

Nationwide flood-frequency reports

The nationwide project consisting of 19 flood-frequency reports, published or to be published as Water-Supply Papers, is nearing completion. Each report is for a part corresponding to a major drainage-basin subdivision of the country used by the U.S. Geological Survey. Sixteen of the 19 reports have been completed; 7 of them had previously been published, and 5 were published this year: Parts 3–A, 4, 8, 9, and 10 (P. R. Speer and C. R. Gamble, r2070; S. W. Wiit ala, r0475; J. L. Patterson, r0687; J. L. Patterson and W. P. Somers, r0352; E. B. Butler, J. K. Reid, and V. K. Berwick, r0348). Four reports are in press: Parts 2–B, 6–A, and 11 (volumes 1 and 2).[19] The remaining three reports are scheduled for completion early in the 1967 fiscal year.

Magnitude and frequency of floods on small streams in North Carolina

A report by H. G. Hinson (r0339) describes methods by which the magnitude of floods from drainage areas ranging between 1 and 150 square miles can be estimated for frequencies ranging between 1.1 and 50 years. The report supplements the more comprehensive nationwide series reports that have been published as water-supply papers. Hinson's report is more applicable to smaller drainage basins than are the reports of the nationwide series.

FLOOD MAPPING

Flood maps of urban areas

Flood-inundation maps showing the limits of inundation of major floods, flood profiles, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Palos Park, Ill., (A. W. Noehre and R. T. Mycyk, r0150); Romeoville, Ill., (A. W. Noehre and G. L. Walter, r0493); Elgin, Ill., (V. J. May and H. E. Allen, r0495); Wheaton, Ill., (V. J. May and H. E. Allen, r0496); Sag Bridge, Ill., (A. W. Noehre and G. L. Walter, r0279); Barrington, Ill., (A. W. Noehre and others, r0497); Fox Lake, Ill., (A. W. Noehre and others, r0148); Tinley Park, Ill., (H. E. Allen, r0225); Blue Island, Ill., (H. E. Allen, r0275); Fort Worth, Tex., (J. H. Montgomery and others, r0494); West Chicago, Ill., (H. E. Allen and V. J. May, r0498); Steamwood, Ill., (V. J. May and H. E. Allen, r0499); Mokena, Ill., (A. W. Noehre, r0276); Lake Calumet, Ill., (H. E. Allen, r0278); and River Forest, Ill., (V. J. May, r0277). A flood-inundation map of the Naperville, Ill., area [20] was published late

[19] H. H. Barnes, Jr. and H. G. Golden, in press, Magnitude and frequency of floods in the United States—Part 2–B. South Atlantic slope and eastern Gulf of Mexico basins (Ogeechee River to Pearl River): U.S. Geol. Survey Water-Supply Paper 1674.

J. L. Patterson, in press, Magnitude and frequency of floods in the United States—Part 6–A. Missouri River basin above Sioux City, Iowa: U.S. Geol. Water-Supply Paper 1679.

L. E. Young and R. W. Cruff, in press, Magnitude and frequency of floods in the United States—Part 11, volumes 1 and 2. Pacific slope basins in California: U.S. Geol. Survey Water-Supply Papers 1685 and 1686.

[20] H. E. Allen and V. J. May, 1965, Floods in Naperville quadrangle Illinois: U.S. Geol. Survey Hydrol. Inv. Atlas HA 154.

in fiscal year 1965, but was released too late to be included in the 1965 summary of Geological Survey activities.

The flood-mapping program in cooperation with the Northeastern Illinois Metropolitan Area Planning Commission, begun in July 1961, is continuing on schedule. As of May 15, 1966, hydrologic atlases had been published for 29 of 43 quadrangles planned for completion.

Work also is currently in progress toward preparation of flood-inundation atlass in Puerto Rico, Texas, Pennsylvania, and New Jersey.

REGIONAL GEOLOGY

Regional geology is a study of geologic and geophysical problems in which maps are required to analyze the problem. The need for geologic maps was recognized in the Organic Act establishing the U.S. Geological Survey, and the mandate given the Survey to complete and maintain modern geologic maps adequate for the needs of the country is a long-range goal. One of the products of the regional geology program is a series of quadrangle maps published at standard scales.

The Geological Survey's regional geology program can be divided into three main elements on the basis of the scale of mapping, which in turn reflects the intensity of study. Most of the program is devoted to detailed studies at scales of 1:24,000 or 1:62,500. Some of these studies are for the purpose of extending the detailed geologic knowledge in areas of known economic interest; others are for the purpose of gaining detailed knowledge for engineering planning or construction in specific localities or areas. Still other mapping studies are carried on with paleontology, sedimentary petrology, or some other specialized topic as the primary objective.

The second largest component of the regional program is systematic mapping and compilation at the intermediate scale of 1:250,000, topographic quadrangle maps at this scale now are available for the entire United States. Both the U.S. Geological Survey and State geologic agencies have recognized the value of geologic and geophysical maps at this scale and have gradually increased their production of such maps. Complete geologic coverage of the United States seems possible in about 20 years if both Federal and State geologic agencies continue to emphasize support of the work.

A small part of the regional-analysis program is devoted to preparation of maps at large scales or to other broad regional compilations. Most of this work is directed toward needs of the earth-science teachers and geologists in the United States.

A summary of recent results of regional studies, particularly in the fields of stratigraphy, structural geology, and regional geophysics, is discussed here according to subdivisions of the conterminous United States shown on figure 2. Additional results with regional significance are given in the section "Paleontology," under "Investigations of Principles and Processes."

INTERMEDIATE-SCALE GEOLOGIC MAPS

Although geologic mapping at a scale of 1:250,000 is a relatively new formal element of the U.S. Geological Survey's program, mapping at this scale has represented a small but significant part of the Survey's geologic studies for many years. Current effort on this intermediate scale of mapping has now expanded to a point where it constitutes about a fifth of the Survey's regional geologic mapping program.

The 1:250,000-scale studies have a variety of uses: (1) they help define areas where the need for larger scale maps is most critical, as for example, in areas where assignments are to be made for new starts in inch-to-the-mile geologic mapping; (2) they direct attention to studies of larger segments of the earth's crust, as in geologic analysis of broad tectonic and stratigraphic problems, in analysis of mineral provinces, and in relating broad geophysical anomalies to surface geology, and (3) they form an integral part of the Transcontinental Geophysical Survey for the International Upper Mantle Project.

The U.S. Geological Survey is now participating in programs designed to provide complete geologic map coverage at a scale of 1:250,000 in the States of Alaska, Nevada, Colorado, and Nebraska. Single-sheet 1° by 2° geologic maps have been started in Washington, Oregon, Idaho, Montana, Wyoming, Utah, Arizona, New Mexico, Iowa, North Carolina, South Carolina, Tennessee, and Virginia. Figure 3 shows the status of 1:250,000 geologic mapping in the conterminous United States and Alaska.

Other intermediate-scale geologic mapping is being done in irregularly shaped areas to provide a geologic framework for mineral appraisals currently underway in primitive areas (see section "Mineral Investigations Related to Wilderness Act"). This geologic mapping will be available for use in compiling 1:250,000 quadrangle maps at a later date.

FIGURE 2.—Index map of the conterminous United States, showing boundaries of regions referred to in discussion of regional geology.

MAPS OF LARGE REGIONS

Geologic and geophysical maps of national or international scope that are published by the U.S. Geological Survey bring together large amounts of geologic information from many sources, including studies by Geological Survey personnel and published and unpublished information supplied by State Geological Surveys, private companies, and universities. Broad geologic patterns and relations illustrated by such maps provide a background on which many kinds of data can be compared and correlated.

Cooperative projects

The Geological Survey collaborates with other national scientific organizations and with international groups in preparing some maps of large regions.

A geologic map of North America, at a scale of 1:5,000,000 (about 1 inch to 80 miles) was released in November, 1965. This map, on which the Geological Survey collaborated, was compiled by a committee of the Geological Society of America, E. N. Goddard, University of Michigan, chairman. It is in two sheets, each measuring 40 by 58 inches, and it shows 105 distinct geologic units, separated first by age and second by origin. Also shown are faults and undersea contours at the margins of the continent.

Other cooperative maps in preparation include:

1. Tectonic map of North America, scale 1:5,000,000. This map is being compiled for the Subcommission for the Tectonic Map of the World, International Geological Congress, under the guidance of P. B. King, U.S. Geological Survey. The map will give a coordinated picture of the tectonics of North America and is expected to influence tectonic concepts and theories in the future; the map may also provide indirect leads to the discovery of new metal, fuel, and other economic provinces.

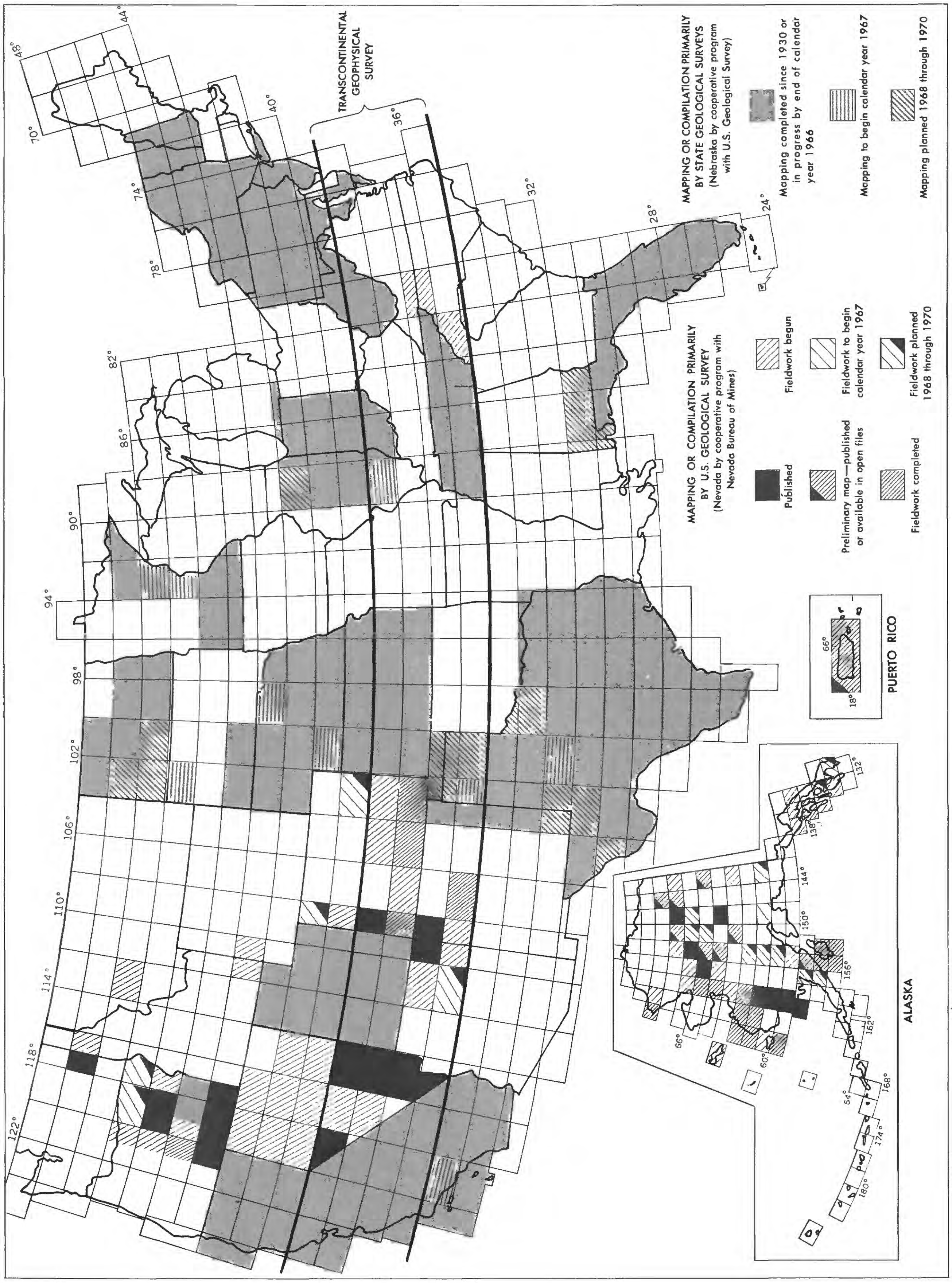

FIGURE 3.—Status of 1:250,000-scale geologic mapping and compilation in the United States, as of June 30, 1966.

2. Metallogenic map of North America, scale 1:5,000,000. This map, the third in the series (after the geologic and tectonic maps) for the International Geological Congress, will relate the mineral deposits of the continent to its major geologic and structural features. Data gathering and compilation have begun under sponsorship of the North American Metallogenic Map Committee, with P. W. Guild, of the U.S. Geological Survey, as chairman.
3. Basement-rock map of North America between lat 20° and 60° N., scale 1:5,000,000. Compilation of this map is by the Basement Rock Project Committee of the American Association of Petroleum Geologists, with P. T. Flawn, University of Texas, as chairman. The map will show the altitude of the upper surface of the basement as determined from wells, geophysical measurements, and geologic inference. Well data used in preparing the map will be published by the American Association of Petroleum Geologists.
4. Basement rock map of the United States, scale 1:2,500,000. This map is sponsored by the Advanced Research Project Agency, Department of Defense, and the compilation is under the direction of W. R. Muehlberger, University of Texas, and R. W. Bayley, U.S. Geological Survey. The map will show outcrops of Precambrian and younger basement rocks, the subsurface extensions of these as inferred from drill holes, the configuration of the basement rock surfaces, and the distribution of intrusive rocks of all ages.

Paleotectonic maps

A program to compile and publish paleotectonic maps of the conterminous United States for each of the geologic systems is continuing. Folios for the Jurassic and Triassic Systems have been published; maps for the Permian System, and a text explaining and documenting the maps, are being readied for publication. Maps for the Mississippian and Pennsylvanian Systems are in preparation. Folios for each system contain maps at a scale of 1:5,000,000 showing the present extent, thickness, and lithofacies of stratigraphic intervals that have been broadly correlated for the country as a whole. A second series of maps at a scale of 1:10,000,000 reconstructs the size, shape, and relative elevation or depth of former areas of land and sea, shows the principal tectonic elements that influenced deposition of the sedimentary rocks, identifies some of the environments of deposition, and shows other features of regional geology.

Lithofacies maps

Lithofacies maps compiled so far for the Mississippian System show that throughout Mississippian time, westward-flowing streams fed sediment to a complex system of deltas that accumulated in western Pennsylvania, West Virginia, and eastern Ohio. In Early Mississippian time, rivers flowing south from Canada built up lesser deltas in southern Illinois, southern Indiana, and parts of Ohio and West Virginia. Sediment discharged from these river systems was not spread westward in any great volume beyond long 90° W. Limestone accumulated in shallow seas that occupied the midcontinent and cordilleran regions. For the most part, the sea floor in these regions was exceedingly flat; structural movements consisted mostly of broad, epeirogenic fluctuations of low amplitude.

COASTAL PLAINS

ATLANTIC COASTAL PLAIN

Stratigraphy of Tertiary and younger rocks in Georgia

S. H. Herrick has delineated the Ocala Limestone, of Eocene age, into two major divisions along a cross section extending from Shell Bluff, Burke County, to Fort Screven, Chatham County, Ga. The upper division, the principal ground-water aquifer in the Savannah area, pinches out inland, updip. Foraminiferal studies show the upper division to be biostratigraphically equivalent to the Crystal River Formation of the Ocala Group of the Florida Geological Survey. The lower division grades updip into the Barnwell Formation in southern Burke and northern Screven Counties, where it constitutes the chief domestic aquifer in this part of Georgia. The lower division is shown to be biostratigraphically equivalent to the Moodys Branch Formation of the Gulf Coastal Plain, again on foraminiferal evidence.

A Pleistocene to Recent foraminiferal assemblage has been identified from a shell deposit from Wilmington Island, Chatham County, Ga. This is the first report of an abundant foraminiferal assemblage of this age in Georgia.

Subsurface studies of Cretaceous rocks in New Jersey

Preliminary findings by H. E. Gill and Donald Langmuir indicate that the Raritan Formation in New Jersey is principally a marine sequence of extensive tabular units, that crop out only in Monmouth, Middlesex, and Mercer Counties, N.J. The Raritan has its greatest subsurface development in Monmouth and Ocean Counties. South of Trenton, the Potomac Group, a fluvial and estuarine sequence, crops out along the Delaware River. The Magothy Formation probably represents a series of coalescing delta deposits between Sandy Hook and Trenton. (For further information see also "New Jersey" in the section on water resources of the Atlantic coast area.)

Potomac Group—Raritan Formation problem

J. P. Owens and J. P. Minard have recognized in New Jersey that the sediments assigned to the Raritan Formation in the west-central part of the coastal plain are lithologically more like Lower Cretaceous Potomac sediments than like the Upper Cretaceous Raritan sediments. A detailed reconnaissance in the northern coastal plain at the type locality of the Raritan Formation revealed that this formation mostly has marine characteristics, in contrast to the fluviatile characteristics of the Potomac Group. Reconstruction of the depositional environments for both the Raritan and Potomac is somewhat simplified by restricting the Raritan only to the lithologies noted at its type locality.

Sandblasted blocks in north-central New Jersey

Sandblasted blocks have been recognized by J. P. Minard (p. B87–B90) from an indurated layer in the Beacon Hill Gravel, of Tertiary age, on a hill within the coastal plain in New Jersey. The blocks are believed to have been sandblasted during the Wisconsin Glaciation when strong winds from a continental ice sheet blew over a sandy surface devoid of vegetation.

Lateral facies changes in Cretaceous and Tertiary formations

Mapping of Cretaceous and Tertiary units from New Jersey to eastern Maryland by J. P. Minard shows lateral facies changes in the formations of this age that in turn indicate changes in depositional environment. A thinner section, composed of shallower water marine sediments makes up the stratigraphic section in the Chesapeake Bay region. The deeper water glauconite beds, which serve as excellent stratigraphic marker horizons in New Jersey, lose their identity in eastern Maryland, where they have a much higher clastic content. These facts suggest proximity to a basement high which presumably underlies much of the coastal-plain area in eastern Maryland.

Domes recognized east of Trenton, N.J.

J. P. Minard and J. P. Owens have recognized two elongate domes in the coastal plain east of Trenton (p. B16–B19). Such structures may be suitable for underground gas storage.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT

Buried Pleistocene valleys near Paducah, Ky.

Investigations by W. W. Olive and W. I. Finch in the Ohio Valley near Paducah, Ky., have revealed additional details of the complex Pleistocene geomorphic history of the Ohio and Tennessee River valleys. Study of drill-hole data as part of the cooperative geologic mapping program between the Kentucky Geological Survey and the U.S. Geological Survey has shown that during late Pleistocene time, valleys in the Paducah area were deeply incised into sands and clays of Late Cretaceous age and were later buried by as much as 200 feet of alluvial and lacustrine deposits.

Drill-hole data from the Ohio River valley below Paducah reveal a broad westerly trending buried valley that was occupied by the Tennessee River at a time when the Ohio River was in the Cache River valley to the north.[21] Deeper and narrowly incised buried valleys in the vicinity of Paducah indicate that this early course of the Tennessee was abandoned and that for a brief time the Tennessee flowed northward to the Cumberland River, which was then tributary to the Cache Valley course of the Ohio River.

Age of glacial lake in western Kentucky and southern Illinois

Prior to the diversion of the lower course of the Ohio River to its present position a lake occupied areas in western Kentucky and southern Illinois.[22] According to carbon-14 evidence reported by W. W. Olive (p. D87–D88) the lake, designated as Lake Paducah, existed during early Woodfordian time of the Wisconsin Glacialtion and probably was not drained until late Woodfordian time or later.

Holly Springs Formation of western Tennessee

Geologic mapping by W. W. Parks reveals that, as shown on geologic maps of western Tennessee, the Holly Springs Sand, first considered as part of the Wilcox Group of early Eocene age and later thought to be part of the Claiborne Group of middle Eocene age, may actually include beds that are stratigraphically equivalent to parts of both groups.

[21] H. N. Fisk, 1944, Geological investigation of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., p. 39 and fig. 42.

[22] W. I. Finch, W. W. Olive, and E. W. Wolf, 1964, Ancient lake in western Kentucky and southern Illinois, *in* Geological Survey Research 1964: U.S. Geol. Survey Prof. Paper 501–C, p. C130–C133.

Cretaceous rocks of pre-Selma age in central Alabama

L. C. Conant completed mapping Cretaceous rocks of pre-Selma age within a belt 25 to 30 miles wide and 100 miles long between the Warrior and Coosa Rivers of Alabama. According to Conant, criteria for distinguishing the Eoline Member and the unnamed upper member of the Coker Formation and the Gordo Formation become less definitive eastward, and boundaries between the units near the Coosa River are vague. *Halymenites* and glauconite, indicative of a marine environment, are common in the Eoline Member in the western part of the belt but are absent in the eastern part. Also, the unnamed upper member of the Coker Formation and the Gordo Formation appear to be much thinner near the Coosa River than in the western part of the belt.

Miocene structural movements in Thomas County, Ga.

Evidence obtained by C. W. Sever (p. C12–C16) during a study of the ground-water resources of Thomas County, Ga., indicates that rocks of Oligocene and Miocene age are gently folded into a northeast-plunging basin and a postulated northeast-trending arch. The two structures are separated by a northeasterly trending fault with beds upthrown on the south side as much as 190 feet. Stratigraphic relations indicate that movement occurred during Miocene time. Inconclusive evidence suggests that folding may have commenced prior to Miocene time. The structures trend parallel to the structural trend of the Appalachian province in Georgia and almost normal to the general northwesterly trending Ocala uplift in Florida.

Structures in northern Mississippi embayment

J. P. D'Agostino and A. V. Heyl report that faults displace the Paleozoic basement and overlying Mesozoic and Tertiary strata at least 100 feet in the northeast-trending New Madrid fault zone of the Mississippi embayment. Published reports, well logs, geomorphic studies using aerial photographs, and cooperative geophysical studies by Lindrith Cordell have helped delimit large uplifted, rotated, and depressed blocks and some of the fault zones in the embayment. They conclude that the region has been repeatedly subjected to major tectonic and seismic disturbances since Mesozoic time, and as recent as the disastrous New Madrid earthquake series of 1811 through 1813. The present most active zone follows the bed of the Mississippi River from Cairo, Ill., southward to West Memphis, Ark., but the part of the embayment east of the river is more stable than that to the west.

NEW ENGLAND AND EASTERN NEW YORK

EASTERN NEW YORK

Rotational fault recognized in Covey Hill area

Covey Hill, which lies on the border between Quebec and New York, near the northeast corner of the Adirondack Mountains, is bordered on the east by the Havelock fault and on the north by the Stockwell fault, according to D. R. Wiesnet and T. H. Clark (p. D35–D38). The Havelock fault is best described as rotational, or pivotal; its hinge point is at or very near the international border. A buried ridge of Precambrian rock may account for localization of the faulting, which probably is Taconic in age.

Aeromagnetic anomalies reflect regional metamorphism in southern Adirondack Mountains

An aeromagnetic map has been compiled for part of the southern Adirondack Mountains by M. E. Beck, Jr. This map shows a pervasive east-west grain which probably reflects regional structural trends. It also is possible to recognize large areas on the map (of the order of 100 square miles or less) within which there is a basic similarity of magnetic pattern, suggesting that the rocks underlying these areas acquired their magnetic characteristics under uniform geologic conditions. Both the regional grain and the boundaries of these "aeromagnetic units" cross mapped geologic contacts, probably because of the effects of regional metamorphism.

Recessional moraines recognized near Plattsburgh

Thick, discontinuous, hummocky masses of drift mapped by C. S. Denny on the northeast side of the Adirondack Mountains near Plattsburgh are recessional moraines deposited during the Pleistocene. They were built near the thin margin of the downwasting ice sheet where its movement was impeded by steep slopes bordering the St. Lawrence-Champlain lowlands. The mountain-front morainic system marks the western edge of a Champlain Valley ice lobe. In Quebec province, N. R. Gadd, of the Geological Survey of Canada, has described a highland-front morainic system that may be of about the same age. The Fort Covington drift of Paul MacClintock, of Princeton University, on the north side of the Adirondacks, is younger.

MAINE

Absence of Taconic unconformity in parts of northern Appalachians

One of the most complete Silurian graptolite sequences in the United States, spanning lower Llandovery to lower Ludlow time, occurs in the Houlton–Smyrna Mills area of northeastern Maine, according to Louis Pavlides and W. B. N. Berry (p. B51–B61). Graptolites of similar Early Silurian age occur close to, and on both sides of, the conformable and gradational contact that separates the dominantly clastic rocks of the Smyrna Mills Formation, of Silurian age, from the underlying limy rocks of the Carys Mills Formation (Louis Pavlides and others, r1735), formerly the ribbon rock member of the Meduxnekeag Formation, of Middle Ordovician to Early Silurian age. The Taconic orogeny, therefore, did not affect this belt of rocks, which regionally make up the Aroostook-Matapedia anticlinorium of the northern Appalachians. This contrasts with the presence of the Taconic break in regions peripheral to the Aroostook-Matapedia anticlinorium.

Eastern boundary of Aroostook-Metapedia anticlinorium

A brief geologic reconnaissance was undertaken by Louis Pavlides, in order to obtain a better understanding of the distribution of the ribbon limestones of the Carys Mills Formation in contiguous terrane in New Brunswick. These rocks generally are in the core of the Aroostock-Matapedia anticlinorium, and their eastern boundary has now been outlined in parts of northwestern New Brunswick (Louis Pavlides, r0133).

Refolded folds in northwestern Maine

Pre-Silurian rocks of the Cupsuptic quadrangle, Maine, studied by D. S. Harwood, show early northeast-trending folds that have been refolded about a steeply plunging regional axis. The first period of deformation produced tightly appressed or isoclinal folds, the axial surfaces of which trended about N. 50° E., and the axes of which plunged gently to moderately northeast or southwest. Late shear folding, due to the upward and southward intrusion of a large adamellite stock, warped the early folds into a regional drag fold with a dextral movement sense and a smaller complimentary structure with a sinistral movement sense. The early folding occurred between late Middle Ordovician and late Early Silurian time. The second deformation is post Silurian and probably Middle or Late Devonian in age.

Serpentinite in pre-Silurian rocks

Serpentinite bodies are more extensive than previously estimated in pre-Silurian rocks in the northern part of the Kennebago Lake and Cupsuptic quadrangles, northwestern Maine, according to E. L. Boudette and D. S. Harwood. Small serpentinite bodies occur in greenstone, but the larger bodies, making up the greatest bulk of the rock, are associated with gabbro. Slip fiber, talc, and nickeliferous carbonate rock are associated with the serpentinite in several places.

NEW HAMPSHIRE

Two tills recognized in Milford region in southeastern New Hampshire

Mapping of glacial deposits of Pleistocene age in the Milford quadrangle by Carl Koteff has outlined sediments laid down in, or graded to, a glacial lake that occupied the valley of the Merrimack River. Lake-level elevations range from about 170–190 feet in the southern part of the quadrangle, to about 230–250 feet in the northern part of the quadrangle, indicating postglacial tilt of between 4 and 5 feet per mile. Two distinct tills that have been observed in many localities in the quadrangle are comparable to those of eastern Massachusetts. The lower till is brown, silty, compact, and shows platiness or foliation; the upper till is gray, sandy, and less compact, and has no apparent platiness or foliation. Borehole information indicates that the lower till becomes gray at depths of about 25 feet. This suggests that the brown till is the oxidized zone of till of an ice advance older than the last Wisconsin ice advance.

MASSACHUSETTS

Fossils in Newbury Formation

At least 23 species of fossils have been collected by N. P. Cuppels from beds of shale, sandstone, and limestone that are interbedded with rhyolitic tuffs in the Newbury Formation of Silurian or Devonian age in the Georgetown quadrangle. However, a Rb/Sr whole-rock age of 350 ± 10 million years (Devonian or Mississippian) has been obtained from 7 samples of the rhyolitic tuff. Mineral alteration by thermal metamorphism in Late Devonian time may account for the younger radiometric age. The faunal and lithologic resemblance of the Newbury to the Pembroke Formation of Silurian age in eastern Maine supports the age inferred from the fossils; the absence of evidence for dynamo-thermal metamorphism implies that the Newbury is post-Acadian, and therefore supports the radiometric age. However, faulting may account for the lack of evidence of Acadian metamorphism in the Newbury.

Faults in eastern Massachusetts

Several zones that contain numerous subparallel northeast-trending faults and associated north-northwest cross faults are demonstrated by N. P. Cuppels in a compilation of recent mapping in eastern Massachusetts. Some strong local contrasts of metamorphic grade of rocks adjacent to the fossiliferous rocks indicate substantial displacement along some of these faults.

Structural features of Hoosac nappe of northwestern Massachusetts

Mapping of the Windsor quadrangle by S. A. Norton shows that the Hoosac nappe is a recumbent fold with several large drag folds on the lower limb. The nappe has a core of Precambrian granitic and plagioclase gneisses. There is no evidence of cross folding of the nappe, although at least two periods of folding are represented in the sedimentary rocks west of the Precambrian core and at least three in the sedimentary rocks east of the core.

Time of emplacement of Shelburne Falls dome

The gneisses in the Shelburne Falls dome in the Heath quadrangle of northwestern Massachusetts are interpreted by N. L. Hatch, Jr., as metamorphosed volcanic rocks of the Middle Ordovician Hawley Schist intermixed with extrusive and intrusive, generally concordant bodies of quartz diorite, probably also of Middle Ordovician age. Unconformably overlying these rocks is a sequence of Silurian and Devonian schists that thin markedly over the area of the dome. This thinning, and the fact that the Silurian and Devonian rocks have themselves been domed up, leads to the conclusion that the doming took place during Silurian and Devonian times as a result of gravitational rise of a body of quartz-diorite magma. This conclusion is supported by geophysical data.

Everett Formation is allochthonous in western Massachusetts

E-an Zen and N. M. Ratcliffe (p. D39–D46) report that the Everett Formation (Ordovician or older) is allochthonous with respect to the underlying Stockbridge Formation (Early Cambrian to Middle Ordovician) and to the Walloomsac Formation (Middle Ordovician) in western Massachusetts and adjoining areas. Carbonate rocks that locally are a breccia and are believed to be blocks of the Stockbridge, occur in a discontinuous zone between the Everett and the Walloomsac. These carbonate rocks are discordant with the surrounding rocks and are believed to be tectonic slivers.

Analysis of aeromagnetic data in western Massachusetts

Aeromagnetic and aeroradioactivity surveys covering approximately 4,500 square miles in western Massachusetts have been flown since 1961. Aeromagnetic anomaly data have provided information on geologic structures and lithologies and have indicated areas of mineralization that may be of economic importance. A current study by R. W. Bromery of the pronounced positive magnetic anomalies associated with three gneiss domes in the vicinities of Shelburne Falls, Goshen, and Woronoco indicates that the rocks of the domes are uniformly magnetized and have a strong polarization direction that deviates significantly from the earth's present magnetic field direction.

Hydrothermally altered argillite and sandstone in Boston

Soft kaolinized argillite and sandstone found in foundation exploration in Boston is probably the result of hydrothermal action, according to C. A. Kaye. The material, which is as much as 200 feet thick, clearly is due to alteration and is not primary as suggested by some earlier workers.

Detrital sillimanite at Third Cliff, Scituate

Very abundant detrital sillimanite in silts and fine sands of probable Eocene age was found by C. A. Kaye at Third Cliff, Scituate. The known bedrock of the area is of low metamorphic grade, but the rocks in the vicinity are masked by thick overburden or are beneath the sea. It is likely that sillimanitic rocks occur nearby and may have resulted from contact metamorphism.

Glacial deposits of Cape Cod

Radiocarbon dates reported by R. N. Oldale on material collected from glacial deposits in the North Truro and Wellfleet quadrangles of Cape Cod range from greater than 25,000 to greater than 32,000 years Before Present on shells, and from 26,000 to greater than 42,000 years B.P. on carbonized wood. All organic material sampled had been transported, and therefore the dates are all greater than the time of advance of the last ice sheet in this area.

Mapping of glacial deposits in the Harwich-Wellfleet area of Cape Cod by R. N. Oldale has redefined units recognized by previous workers, and has identified some new units. The east part of the Sandwich moraine appears to be simply the collapsed head of an outwash plain deposited from the Cape Cod Bay ice lobe. The later stratified drift deposits of Outer Cape Cod were laid down by melt waters from an ice lobe east of Cape Cod; the successive bodies are distinguished by pebble lithologies as well as by topography.

Discontinuous layers of till and till-like material on outwash in the Chatham-Orleans area may be one or more mudflows from ablation moraine, rather than till deposited by an ice readvance.

Carl Koteff has found a fossil ice-wedge structure in the Harwich quadrangle. The structure, at least 10 feet deep and filled with eolian and glaciofluvial sand, is the first known from Cape Cod, and this locality is only the third known in Massachusetts. Because the formation of ice wedges requires the presence of permafrost, this structure indicates that the periglacial climate must have had a mean annual temperature at least 20°F below the present mean annual temperature of about 50°F.

CONNECTICUT

Thrust faults in eastern Connecticut

A complex fault system has been mapped in the upper plate of the large thrust sheet of the Plainfield-Danielson-Putnam area by H. R. Dixon. Small-scale thrust faults, subparallel to and probably contemporaneous with the major thrust fault, have a general north-northeast strike, and dip 10°–25° east. Branching from the thrust fault are steeply dipping faults, most of which trend northwest. Vein quartz that was found along a north-trending steeply dipping fault in southern Plainfield is similar to the pure silica quartz of Lantern Hill, North Stonington, which is currently being mined for silica glass. The vein quartz in Plainfield may provide a new source for silica.

Marble beneath Lake Waramaug, west-central Connecticut

According to R. B. Colton, the results of recent excavation and drilling along the shore of Lake Waramaug, near New Preston, indicate that the lake is underlain by a belt of marble 2 or 3 miles long and perhaps half a mile wide. This marble is tentatively correlated with the Stockbridge Formation of Early Cambrian to Middle Ordovician age that crops out nearby. The origin of Lake Waramaug was difficult to explain prior to the discovery of the presence of marble, because the lake overflows across a bedrock lip and not across a dam composed of glacial debris. The lake occupies a bedrock basin at least 40 feet deep, which came into existence as a result of solution of the marble during Tertiary time and glacial erosion during Pleistocene time.

Major lineament of eastern Connecticut extends into Rhode Island

The major east-trending lineament discovered in eastern Connecticut from aeromagnetic data by R. W. Bromery is now known to extend east across Rhode Island beyond Newport, for a total distance of at least 90 miles. The lineament abruptly truncates the magnetic anomaly correlated with the large mass of gabbroic rocks near Preston, Conn. Contoured aeroradioactivity data in southeastern Connecticut also shows evidence of the lineament.

Two tills near Pomfret

Two tills exposed in Pomfret, and studied by Fred Pessl, Jr., (p. D89–D93) were deposited by different advances of glacier ice, separated by an interval of weathering. The upper till is unoxidized, light gray, crudely stratified, sandy, and contains lenses of well-sorted, stratified sand and gravel; its fabric has a preferred orientation of S. 15°–35° W. The lower till is oxidized, olive brown, very compact and more silty; its fabric has a preferred orientation of S. 5°–15° E. The two tills are separated by well-sorted, fine-grained, unoxidized, stratified sediments that contain fragments of the lower till, and are strongly folded and faulted.

Site evaluated for 200-Bev accelerator in east-central Connecticut

An area near Plainfield was one of many given consideration as a possible site for a 200-Bev accelerator. The basic geologic requirements were studied by J. H. Hartshorn, based on previous work of A. D. Randall, and by H. R. Dixon. The Connecticut Development Commission was given the geologic and water-resource data to aid in its presentation to the Atomic Energy Commission site-study team.

Sand and gravel resources

A summary by L. R. Page of work in Connecticut shows that about 2 billion cubic yards of sand and gravel resources were outlined by mapping during 1965.

APPALACHIAN REGION

PENNSYLVANIA AND NEW JERSEY

Regional joint system in anthracite region

G. H. Wood, Jr., H. H. Arndt, and M. D. Carter report that joints in rocks of Early Silurian to Late Pennsylvanian age in the western part of the anthracite region of eastern Pennsylvania are systematically related to the complex fold system. One set is nearly parallel to the regional structural grain, whereas the other is nearly perpendicular to it. It is believed that these joints formed both before and during the early stages of folding. Their trends are remarkably similar to joint sets reported by earlier workers elsewhere in the Valley and Ridge and Appalachian Plateaus provinces of Pennsylvania and southern New York and suggest that a regional joint system prevails throughout much of these provinces in both States.

Complex deformation in northern anthracite field

Detailed mapping by M. J. Bergin shows that the southwestern end of the synclinorium containing the Northern Anthracite field in northeastern Pennsylvania is much more complexly deformed than previously reported. Here, second-order structures include two tightly folded, eastward-plunging synclines, an easterly elongated basin, a broad intervening anticline and associated thrust and high-angle reverse faults with as much as 500 feet of throw, and at least one folded thrust of undetermined transport. A preliminary interpretation suggests a tectonic history beginning with regional warping, followed by thrust faulting about parallel to bedding planes, intense folding (in part disharmonic), and finally, high-angle thrust faulting. This history can be related to the first three tectonic stages postulated by Arndt and Wood for the anthracite region of eastern Pennsylvania.[23]

A nappe de recouvrement

Detailed geologic mapping in eastern Pennsylvania and western New Jersey by A. A. Drake, Jr., R. E. Davis, and J. M. Aaron combined with aeromagnetic studies by R. W. Bromery has shown that the Precambrian crystalline rocks of the Reading Prong are allochthonous. Regional geometric and stratigraphic relations suggest to Drake that these Precambrian rocks form the core of a major nappe that has a width of more than 15 miles. This core, and the Cambrian and Ordovician rocks in the inverted limb, have been refolded so that Precambrian rocks lie in the trough of synforms and form the ridges of the Prong. The valleys are underlain by carbonate rocks and by the Martinsburg Formation brought to the surface in antiforms which are cored by the stratigraphically youngest rocks. In the area mapped to date, the Martinsburg Formation of the Pennsylvania slate belt lies at the brow and in the normal limb of the nappe. As rocks not younger than Ordovician are involved in the structure, the nappe must date from the Taconic orogeny. The refolding of the core and inverted limb cannot be dated directly, but probably is a result of the Appalachian orogeny.

[23] H. H. Arndt and G. H. Wood, Jr., 1960, Late Paleozoic orogeny in eastern Pennsylvania consists of five progressive stages: Art. 81 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B182–B184.

Gravity studies in Reading Prong and Triassic basin

Analysis of regional gravity data by R. W. Bromery indicates that Precambrian rocks at the west end of the Reading Prong have a limited vertical extent. This agrees with information gained from an aeromagnetic survey of the same area and supports the interpretation that the prong is allochthonous (see preceding section). In addition, steep east-trending gravity gradients occur in the Triassic basin near Doylestown, Birdsboro, and Mount Hope, Pa. These anomalies are interpreted as reflecting profound faulting in the pre-Triassic rocks in the basin floor.

Martinsburg Formation is tripartite in Pennsylvania slate belt

Detailed geologic mapping by A. A. Drake, Jr., J. B. Epstein, and R. E. Davis, in the slate belt of eastern Pennsylvania has shown that the Martinsburg Formation, of Ordovician age, consists of a lower thin-bedded, cyclic, claystone slate member, a middle unit of alternating claystone slate and graywacke or graywacke siltstone, and an upper unit of thick-bedded, cyclic, claystone slate, similar to the units defined by Behre.[24] The commercial slate is confined to the upper member and the upper part of the middle member, which disappear along the Taconic unconformity east of the Delaware River and west of Slatington, Pa.

Tectonic styles in easternmost Pennsylvania

Structural analysis by J. B. Epstein and A. A. Drake, Jr., shows that folding is disharmonic between four contrasting sequences of Ordovician through Devonian rocks in easternmost Pennsylvania. Each sequence has a different fold style that is apparently related to its lithic character. Each sequence has been deformed semi-independently of rocks above and (or) below and is presumably set off from other sequences by a décollement.

Origin of wind and water gaps in Stroudsburg area

Wind and water gaps in the Stroudsburg area of eastern Pennsylvania and northern New Jersey occur where resistant rocks dip steeply and are narrow, where folds end over short distances, or in places of local intense folding. The gaps are athwart the trend of ridges and parallel to major cross-joint sets. J. B. Epstein (p. B80–B86) interprets these relationships as indicating structural control in the localization of these gaps rather than their having formed through regional superposition of streams upon resistant rocks.

[24] C. H. Behre, Jr., 1927, Slate in Northampton County, Pennsylvania: Pennsylvania Geol. Survey Bull. M9, 308 p.

Residual clay deposits in eastern Pennsylvania

Residual clay deposits of commercial importance have been developed from limy shales and shaly limestone on Cherry and Chestnut Ridges, Monroe County, Pa. These deposits are located southwest of the Wisconsin terminal moraine and are believed by J. B. Epstein to have formed during pre-Wisconsin weathering. No clay deposits are present northeast of the moraine, and it is presumed that any clay that formed was stripped away during the Wisconsin glacial advance.

MARYLAND

An unroofed gneiss dome in Maryland Piedmont

D. L. Southwick has found that staurolite and kyanite isograds in the Wissahickon Formation of early Paleozoic(?) age, of the central Maryland Piedmont are generally rudely concentric about mantled gneiss domes. Recent work shows that these isograds enclose an area in western Harford County within which no rocks older than Wissahickson are exposed, and may indicate a gneiss dome that has not as yet been unroofed by erosion. Aeromagnetic data support this interpretation.

Geophysical survey of Harford County

Airborne radioactivity and aeromagnetic anomaly patterns in Harford County, Md., are interpreted by R. W. Bromery to indicate that the metamorphic rocks of the Piedmont are cut by numerous mafic intrusive bodies. In addition, it was found that the Sykesville Formation, of Paleozoic age, is extremely magnetic. Thin-section study shows that the formation contains abundant, well-formed magnetite octahedra.

VIRGINIA, WEST VIRGINIA, TENNESSEE, AND NORTH CAROLINA

Lee Formation in Virginia and West Virginia

Stratigraphic studies of rocks of Carboniferous age by K. J. Englund and A. O. DeLaney show that quartzose conglomeratic sandstone, the dominant lithology of the Lee Formation, tongues out northeastward in southwestern Virginia (p. D47–D52). In adjoining parts of Virginia and West Virginia, stratigraphic equivalents of the unit include parts of the Pennington, Pocahontas, and New River Formations.

Thrust-fault relationships in southern Appalachians

Recent mapping in the Mount Rogers area of Virginia and Tennessee by D. W. Rankin necessitates a reinterpretation of the geologic structure at the northeast end of the Mountain City window. The Catface fault is not, as shown by King and Ferguson,[25] continuous with the Iron Mountain fault around the northeast end of the window, but is a separate fault that overrides the Iron Mountain fault. The Catface fault is a member of the Stone Mountain fault family and has been traced to a point about 5 miles beyond the end of the Mountain City window, where it is overridden in turn by a still higher member of the Stone Mountain fault family.

D. W. Rankin reports that the Mount Rogers Volcanic Group, of late Precambrian age, formerly thought to be restricted to the Shady Valley thrust sheet, is now known to be part of the Blue Ridge thrust sheet lying above the Stone Mountain fault proper. Rocks of the group also occur in several slices between the Blue Ridge and Shady Valley thrust sheets.

Revision of Nantahala Slate in Murphy syncline

In the course of their mapping of the Knoxville 2° quadrangle (1:250,000 scale) of North Carolina and Tennessee, J. B. Hadley and A. E. Nelson have found that the Nantahala Slate, of early Paleozoic(?) age, as mapped by Arthur Keith in 1892–1904, is a distinctive dark-gray slate or siltstone that contains thin light-colored quartzite beds intercalated at several stratigraphic levels. At some places the quartzite is thick bedded and is the dominant lithology in sections as much as 200 to 300 feet thick. Such units were mapped by Keith as Tusquitee Quartzite. It is suggested that the quartzite be regarded as interbeds in the Nantahala and that the term Tusquitee no longer be used in North Carolina. In addition, Keith mapped as Nantahala the gray micaceous schists that are generally sulfide bearing in several places far from the Murphy syncline. These rocks lack the intercalated quartzite described above, and they are included by Hadley and Nelson as part of the Great Smoky Group, resembling the dark sulfidic and carbonaceous rocks of the Anakeesta Formation.

Brevard fault zone extended to the northeast

In his mapping of the Winston-Salem quadrangle (1:250,000 scale), G. H. Espenshade has traced the Brevard fault zone about 20 miles northeast from the Grandfather Mountain area of North Carolina, where it has been mapped by J. C. Reed, Jr., and Bruce Bryant. He has also found that the rocks in the vicinity of the zone near North Wilkesboro, N.C., are generally similar to those exposed in the Grandfather Mountain area, but there are some problems in correlation that will need further study.

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[25] P. B. King and H. W. Ferguson, 1960, Geology of northeasternmost Tennessee: U.S. Geol. Survey Prof. Paper 311, 136 p.

Carolina slate-belt rocks occur west of Gold Hill fault

Recent mapping in Cabarrus County, N.C., by H. W. Sundelius has shown that basaltic tuffs and flows, tuff breccia, and rhyodacitic crystal lapilli tuffs typical of the Carolina slate belt crop out west of the Gold Hill fault zone. These slate-belt-like rocks are intruded by plutons of diorite-gabbro and quartz monzonite of Charlotte belt affinities. West of these plutonic rocks is a complex assemblage of schist and amphibolite intimately associated with coarse-grained, in part nearly pegmatitic, granite that is rich in potassic feldspar.

Formation of phyllonites in Grandfather Mountain area

Bruce Bryant (p. D144–D150) reports that phyllonites of the Grandfather Mountain area, North Carolina, produced during Paleozoic low-grade metamorphism of Precambrian granitic rocks and gneisses, were formed in chemical systems generally open to K, Na, Ca, and H, and locally open to a number of other components. Hydrolysis of feldspars was the principal reaction affecting the alkali content of the phyllonites. Changes in chemical and mineral composition of the rock in the phyllonite zones were probably controlled through a combination of intense shearing and type and availability of solutions.

Porous stromatolite zones in Copper Ridge Dolomite

Recent study of outcrops of Copper Ridge Dolomite, of Late Cambrian age, along the south shore of Norris Reservoir in Claiborne and Union Counties, Tenn., by L. D. Harris (p. C48–C53) has pointed up the occurrence of abundant vugs in massive algal stromatolite zones. Examination of cuttings from an oil well drilled in Lee County, Va., about 26 miles northeast of the Norris Reservoir section, indicates that small vugs and intercrystalline voids occur in several zones in the Copper Ridge. The thickest and most abundant zones appear to correlate with laterally persistent stromatolite zones in the lower half of the Copper Ridge in the Norris Reservoir section. The persistence of porous zones into the subsurface offers a potential site for the accumulation of hydrocarbons in this part of the Copper Ridge Formation.

GEORGIA

Brevard fault zone near Atlanta

M. W. Higgins has found that the Brevard fault zone near Atlanta contains both isoclinally folded metasedimentary rocks and sheared and retrogressively metamorphosed rocks. The sheared rocks resemble rocks described from other localities along the zone, and their presence supports the interpretation that the Brevard is a major fault zone. The attitude of lineations within the zone suggests that, in this area, the latest movement had a thrust component; however, major strike-slip movement may have occurred earlier.

EASTERN PLATEAUS

NEW YORK

Bois Blanc Formation in western New York

Biostratigraphic studies by W. A. Oliver, Jr., have shown that the oldest Devonian deposit in western New York, the *Amphigenia* zone, is the eastern featheredge of the Bois Blanc Formation of the Michigan basin. The formation is distinguished from the overlying Onondaga Limestone in western New York by significant lithic and faunal differences. Basal sands in both the Bois Blanc and Onondaga were apparently reworked from the older Oriskany Sandstone. Both lithic and faunal evidence suggest that the Bois Blanc and Onondaga are separated by a disconformity.

Distribution of limestone erratics in drift of south-central New York

In the Susquehanna River valley in New York, between Binghamton and Waverly, P. R. Seaber and E. F. Hollyday report that the hardness of water in deeply buried drift is significantly less than the hardness in shallow drift. A previous study correlated high values of hardness with drift containing many limestone erratics, and low values of hardness with drift containing few or no such erratics. This new information on stratigraphic contrast of water hardness indicates that drift with limestone erratics overlies drift virtually free of limestone erratics in the Susquehanna River valley between Binghamton and Waverly.

PENNSYLVANIA

Discordance at Mississippian-Devonian boundary in north-central Pennsylvania

Recent mapping by G. W. Colton in parts of Clinton, Lycoming, and Tioga Counties, Pa., suggests a discordance near the Mississippian-Devonian boundary. Bedding-plane attitudes in the Upper Devonian Catskill Formation are generally steeper than those on the overlying Lower Mississippian Pocono Formation as determined from structure contours drawn on top of the Pocono. The discordance may be mainly structural if the Catskill, which is thinner bedded and more heterogeneous in composition than the Pocono, yielded differently to deforming forces than did the Pocono. On the other hand, the discordance may have resulted from uplift along present anticlinal axes while the sediments were accumulating.

Coal beds thickest in bands parallel to basin margin in southwestern Pennsylvania

On the northeast side of the Dunkard basin in Washington and Greene Counties, southwestern Pennsylvania, and adjacent areas, major coal beds from the Pittsburgh coal bed of Pennsylvanian age up to, and including, the Washington coal bed of Permian age have been found to be thickest in zones or bands about parallel to the periphery of the basin. Surface and subsurface studies by B. H. Kent, S. P. Schweinfurth, and J. B. Roen have shown that these bands of maximum thickness are on the order of two 7½-minute quadrangles (7 to 14 miles) wide and that the band of each succeeding coal bed below the stratigraphically highest, Washington coal bed, occurs farther outward from the center of the basin. Areas of thickest Waynesburg coal form a band 6 to 10 miles wide at an intermediate distance from the center of the basin. The Uniontown, Sewickley (Mapletown), and Redstone coal beds form the bands farthest from the center of the basin. These three coal beds are either thin or absent over most of the central area of the Dunkard basin. Where they first occur in significant thicknesses toward the east the precise positions and widths of these bands of thickest coal are difficult to determine because of folding and erosion. Correlative coal beds along the northwest side of the basin in Belmont County, Ohio, may occur in similar bands.[26] Regional compilation of coal thicknesses indicates that bands of maximum coal thickness may close around the north end of the Dunkard basin.

KENTUCKY

Pre- and post-Middle Devonian faulting

Faults along the east flank of the Cincinnati arch in Kentucky have been active prior to and following the development of the unconformity at the base of Devonian strata. Isopach maps of the Palmer and Union City quadrangles prepared by G. C. Simmons while working on the cooperative mapping program of Kentucky by the Kentucky Geological Survey and U.S. Geological Survey have demonstrated that considerably greater stratigraphic throw occurs below the pre-Devonian unconformity than above it along northwest-trending faults (p. C17–C19). The older faulting took place between Middle Silurian and Middle Devonian time. The later faulting occurred sometime after deposition of the lower half of the New Albany Shale and presumably is younger than Middle Devonian. The upper part of the New Albany Shale, and younger strata, have been removed by erosion from the faulted areas. The pre-Devonian movement has been recognized by Jillson,[27] but the repeated movements seemingly have not been described.

Stream anticlines in central Kentucky

G. C. Simmons has described (p. D9–D11) small nontectonic folds, called stream anticlines, that occur in interbedded limestone and shale in eastern Kentucky. These folds, which normally have an amplitude of only a few feet, may be as much as half a mile long. They are not related to tectonic features, and their general localization along valley bottoms suggests a Recent origin.

Tongue of Illinoian ice in Ohio Valley

Studies by L. L. Ray (p. B91–B94) suggest that glacial deposits on the uplands of southeast Indiana east of Madison are pre-Illinoian. If this is correct, those deposits separate Illinoian drift to the north from small masses of drift considered to be Illinoian in the Ohio Valley to the south. As glacial deposits in the region are generally successively younger northward, Illinoian drift in the Ohio Valley south of pre-Illinoian drift is in an anomalous position. Possibly the drift in the valley was deposited from a tongue of ice moving ahead of the main ice sheet down the Miami River into the Ohio Valley and down it to about the mouth of the Kentucky River.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY

MINNESOTA AND MICHIGAN

Orientation of paleomagnetic fields near Lake Superior

K. G. Books and M. E. Beck, Jr., have observed close similarity of remanence directions of the paleomagnetic fields in lavas near Grand Marsis, Minn., and in lavas of middle Keweenawan age near Calumet, Mich. This suggests approximately equivalent time of extrusion and supports the possibility of a correlation through paleomagnetic data.

The directions of reversed remanence occurring in magnetic grains in flows near Ironwood, Mich., and of normal remanence in flows near Calumet are dissimilar and suggests that these lava accumulations were separated by a large interval of time. Furthermore, the difference in directions is much greater than all fluctuations of the paleomagnetic field in the entire columnar section of middle Keweenawan flows

[26] H. L. Berryhill, Jr., 1963, Geology and coal resources of Belmont County, Ohio: U.S. Geol. Survey Prof. Paper 380, 113 p.

[27] W. R. Jillson, 1964, Discovery of mid-Paleozoic faulting in eastern-central Kentucky: Frankfort, Roberts Printing Co., 13 p.

at Calumet and suggests that the interval of time separating these episodes of extrusion was much greater than that required for accumulation of all the flows at Calumet. An alternate explanation of the disagreement requires a more widely fluctuating geomagnetic field in early middle Keweenawan time, but not enough data are presently available from the Ironwood area to support either an unprecedented secular variation or longer range "polar wandering."

Angular unconformity in Gogebic district, Michigan

An angular unconformity between the Bad River Dolomite and the overlying Palms Quartzite, both of Animikie (middle Precambrian) age, has been found near the eastern end of the Gogebic iron-bearing district, Michigan, by W. C. Prinz. An unconformable separation of these units has long been known, but no angular discordance had been observed. The angular relations suggest that the absence of lower Animikie rocks in much of the Gogebic district is due to pre-Palms tilting and erosion rather than to nondeposition.

Structure complexities identified in area south of Gogebic district

Three faults of moderate to large displacement have been tentatively recognized by C. E. Fritts in the Marenisco-Watersmeet area, southeast of the Gogebic iron district, Michigan. A northeast-trending thrust fault near Marensico truncates as much as 12,000 feet of the middle Precambrian Tyler Slate (Animikie Series) in this area, and the fault may account also for anomalous dips in the Keweenawan Series east and west of Lake Gogebic. About 8 miles to the southeast, a northeast-trending fault displaces rocks of the Keweenawan Series about ¾ mile in a left-lateral sense and about 1,000 feet vertically. An inferred east-trending fault near Thayer, in metavolcanic rocks of the Animikie Series, has an apparent right-lateral offset of 5 miles. Vertical displacement on this fault may be several thousand feet in the area north of Watersmeet, where it seems to form the boundary between a granitic body and Michigamme Slate. The fault also marks the boundary of an area of positive magnetic anomalies according to the interpretation of J. E. Case, W. C. Prinz, and C. E. Fritts. A preliminary whole-rock Rb-Sr age determination by Z. E. Peterman indicates that the granitic gneiss near Watersmeet may have been emplaced about 1.8 billion years ago, approximately coincident with the regional metamorphism of the Animikie Series rather than being a pre-Animikie unit as inferred by previous investigators.

Biostratigraphic subdivision of Decorah Shale

The Decorah Shale, of Middle Ordovician age, can be divided southeast of St. Paul, Minn., into three biostratigraphic zones on the basis of a study of bryozoans by O. L. Karklins. The lower zone in Minnesota is the approximate biostratigraphic equivalent of the Spechts Ferry Shale Member of the Decorah in Illinois, Wisconsin, and Iowa. The bryozoans of the Decorah Shale appear to be more closely related to those in the Trenton Limestone of New York than to those in the Black River Group of that State. New data obtained during a study of bifoliate cryptostome bryozoans in the Decorah Shale also led to revisions in the generic and suprageneric classification of the families Rhinidictydae, Stictoporellidae, and Ptilodictyidae.

WISCONSIN

Remanent magnetization studies of Keeweenawan gabbro

K. G. Books, W. S. White, and M. E. Beck, Jr., have analyzed the direction of remanent magnetization of gabbros in northern Wisconsin with respect to establishing the time of emplacement of the gabbro (p. D117–D124). They conclude that the baggro was emplaced during the late Keeweenawan, after the lavas it intrudes had been tilted.

NORTHERN ROCKY MOUNTAINS AND PLAINS

WASHINGTON

Early Cretaceous thrust fault in northeastern Washington

Low-grade metasedimentary rocks of the Covada Group along the Columbia River, from near Kettle Falls to north of the mouth of the Spokane River, were thrust eastward over high-grade metasedimentary rocks of early Paleozoic or Precambrian age, probably in Early Cretaceous time, according to G. E. Becraft. The fault, exposed only in the Twin Lakes quadrangle, now dips about 10° to 25° eastward as the result of tilting and gentle warping subsequent to the thrusting, and is cut by a granodiorite pluton of Cretaceous(?) age.

Little or no lateral movement along Republic graben faults

Correlation of a sequence of metasedimentary rocks more than 10,000 feet thick in the Togo Mountain quadrangle of Ferry County, with the metamorphic rocks of Tenas Mary Creek west of the 6-mile-wide Republic graben, by R. C. Pearson, indicates that little or no lateral movement occurred along the graben faults.

Glacial deposits more than 780 feet thick near Spokane

D. R. Cline reports that a well just north of Spokane bottomed at 780 feet in glacial deposits, indicating an old valley at least 600 feet deeper than the present valley where the Spokane River flows from the glacial deposits onto basalt. Ground water moves from the Spokane Valley northward to the Little Spokane River suggesting that the preglacial river turned northward from Spokane and followed the deep valley to the Little Spokane River and then turned westward and cut the present narrow valley of the Little Spokane.

IDAHO

Tension fractures in Purcell Trench caused by movement along Hope fault

Detailed mapping by J. E. Harrison north of Lake Pend Oreille in Bonner County shows that right-lateral movement on the northwest-trending Hope fault resulted in tension fractures that trend northward up the Purcell Trench. Dilation was accompanied by intrusion of lamprophyre and granodiorite porphyry dikes that fill most of the faults in the Purcell Trench.

Recent faulting in central Idaho

Hackly topography in the Yellow Pine area is the expression of fine-scale block faulting of recent origin superimposed on a fault system formed mainly in the Tertiary, according to B. F. Leonard. Three lines of evidence show that faulting has continued almost to the present: (1) anomalous rock ridges 50–75 feet high interrupting smooth slopes with 35°–40° gradients; (2) hillocks of plutonic rocks in the sandy flats of the Johnson Creek graben; and (3) abrupt changes in direction and gradients of small streams "stepped" late(?) Pleistocene moraines. Slight adjustments may still be taking place.

Precambrian rocks of east-central Idaho subdivided

In the central part of the Lemhi Range, E. T. Ruppel has been able to subdivide the little known Precambrian sequence of fine- to medium-grained feldspathic quartzites, long considered part of the Belt Series, into 8 mappable units totaling at least 25,000 feet in thickness.

Kinnikinic Quartzite separated into three distinctive units

Kinnikinic Quartzite in the Clayton quadrangle of Custer County, being mapped by S. W. Hobbs and W. H. Hayes, comprises three distinctive units. The top unit is pure fine-grained quartzite about 1,000 feet thick; the middle unit is coarser grained, locally conglomeratic, feldspathic quartzite more than 2,000 feet thick, containing shaly zones and at least one carbonate bed; and the bottom unit is silty quartzite and platy siltstone underlain by clean, medium- to coarse-grained, gray to tan and purplish, nonfeldspathic quartzite. Fossils from the uppermost unit are dated as Middle Ordovician by R. J. Ross, Jr. and J. W. Huddle, and fossils from near the top of the lowermost unit were determined by A. R. Palmer as Middle Cambrian.

Folded thrusts in lower Paleozoic rocks of east-central Idaho

Folded thrust faults subparallel to bedding in Devonian and older Paleozoic rocks in a zone that may extend from the Idaho batholith on the west to the Beaverhead Range on the east, north of the Snake River Plain, have been recognized by W. J. Mapel and C. A. Sandberg. The faults apparently have doubled or tripled the thickness of Devonian rocks in the southern Lost River Range.

Mapel and Sandberg also discovered a sinkhole deposit of the Lower Devonian Beartooth Butte Formation on Hawley Mountain in the Lost River Range, 200 miles west of previously known occurrences of this formation. The sinkhole is 1,400 feet wide at the top and extends downward at least 900 feet through Silurian into Ordovician rocks.

Geology revised in southeastern Idaho

Most rocks mapped earlier as belonging to the Wayan Formation of Early Cretaceous age in the Freedom quadrangle are shown by S. S. Oriel and L. B. Platt to be rocks of the Upper Jurassic Preuss and Stump Sandstones and of the Lower Cretaceous Gannett Group. Farther south, newly recognized thrust slices have been mapped; the entire Giraffe Creek syncline and the block of Stump Sandstone north of Elk Valley, east of Cozzens Ranch, are probably part of a thrust slice of the Meade fault.

MONTANA

Cambrian rocks identified west of Missoula

Cambrian rocks in the Alberton quadrangle, being mapped by J. D. Wells, consist of Flathead Quartzite about 80 feet thick, overlain by green micaceous glauconitic shale about 130 feet thick, "blue and gold" limestone about 420 feet thick, Hasmark Formation 1,580 feet thick, and Red Lion Formation about 420 feet thick. Fossils, identified by A. R. Palmer, establish a Middle Cambrian age for the glauconitic shale and "blue and gold" limestone and indicate that these rocks can be correlated with the Gordon Shale and Damnation Limestone.

Buried plutons and lead-zinc mineralization in Sun River area

Geophysical studies by D. R. Mabey and D. L. Peterson in the disturbed belt of the Sun River area of central Montana being mapped by M. R. Mudge show gravity lows just east of gravity highs south of Sun River, suggesting the presence of buried plutons. Geochemical studies by R. L. Erickson and Mudge disclosed a northwest-trending belt of weak lead and zinc mineralization east of the gravity anomalies. R. E. Zartman determined that lead from two of the deposits, in Precambrian rocks, is of B type, and that lead from the other two deposits, in Cambrian and Devonian rocks, is of J type.

East-northeast-trending weakness zone in basement in northern Montana

Ultramafic and mafic alkalic igneous rocks in the diatremes southeast of the Bearpaw Mountains, in the Little Rocky Mountains, and in the Haystack Butte chonolith are believed by B. C. Hearn, Jr., to indicate a basement weakness or fracture that allowed ascent of deep-seated magma in a zone trending east-northeast for 90 miles in north-central Montana.

Hearn also found that beds believed to be Fort Union Formation (Paleocene), preserved as down-faulted slices in diatremes near the Little Rocky Mountains, contain fragments of rocks typical of those exposed in the core of the Little Rocky Mountains; this suggests that at least part of the intrusion and uplift of the Little Rocky Mountains occurred in the Paleocene or earlier.

Source for Late Cretaceous volcanic breccia in west-central Montana

Andesitic and rhyodacitic volcanic breccias in the Two Medicine Formation of Late Cretaceous age become progressively coarser grained from northeast to southwest in the Roberts Mountains quadrangle, according to R. G. Schmidt. This progressive coarsening indicates that the source of these volcanic rocks is to the southwest, either under the Belt Series, which has been thrust over the Two Medicine Formation there, or much farther south in the Elkhorn Mountains. Schmidt has correlated the volcanic member of the Two Medicine Formation with the Elkhorn Mountains Volcanics on the basis of similar lithology and stratigraphic position.

New correlations of Precambrian rocks in western Montana

M. R. Klepper, mapping the Butte quadrangle (1:250,000 scale), has found that the Spokane Formation in the Phillipsburg area is the equivalent of the Miller Peak, Bonner, and McNamara Formations to the north and northwest but is not equivalent to the Spokane Formation of the type area in the Spokane Hills. Also, the Miller Peak and Bonner Formations west of the Continental Divide are correlatives of the Marsh and Greenhorn Mountain Formations of the Helena area.

Partial section for Precambrian rocks east of Dillon

A partial stratigraphic section for the Precambrian metamorphic rocks in the Christensen Ranch quadrangle east of Dillon in Madison and Beaverhead Counties has been established by H. L. James and K. L. Wier. Their mapping also shows that east-trending isoclinal folds have been refolded along north-trending axes.

Regional unconformity forms Mississippian-Pennsylvanian boundary

E. K. Maughan and A. E. Roberts report that the Mississippian-Pennsylvanian boundary in Montana is a regional unconformity. They redefine the Big Snowy Group to include the Kibby, Otter, and Heath Formations, as it was originally established, and restrict it to rocks below the unconformity. Following regional upwarp and erosion in Late Mississippian time the area gradually was submerged during Early Pennsylvanian time. Rocks of the Pennsylvanian Amsden Group were deposited unconformably on Upper Mississippian rocks in central Montana and on older rocks in southern Montana and northern Wyoming.

NORTH DAKOTA, SOUTH DAKOTA, AND NEBRASKA

Lake Milnor beaches are actually ice-marginal deposits

Ridges of sand and gravel in southern North Dakota, believed by earlier workers to be beach deposits along Lake Milnor, a lake that predated Lake Agassiz, are part of a much larger deposit extending from the Sheyenne River to Lake Traverse according to C. H. Baker, Jr. (p. B77–B79). He indicates that the deposits were formed in an ice-marginal channel rather than along a lake.

Lateritic soil profile under Chadron Formation

A widespread lateritic soil profile underlies the Chadron Formation (Oligocene) in western South Dakota and northwestern Nebraska, according to W.

A. Pettyjohn (p. C61–C65). The soil profile formed on stratigraphic units ranging in age from Late Cretaceous to late Eocene.

Metasedimentary amphibole schists in Black Hills

Amphibole schists of Precambrian age that commonly grade into metamorphosed impure calcareous sedimentary rocks in the Bear Mountain area of the central Black Hills of South Dakota are believed by J. C. Ratté to have formed largely from volcanic ash deposited in water and mixed with other sedimentary deposits; a few more massive amphibole-rich units may have been mafic lava flows. Some schists contain thin laminae that appear to be sedimentary layers, and many contain quartzose beds a few inches thick.

WYOMING

Beartooth Mountains formed by vertical uplift

Geologic studies by W. C. Pierce indicate that the Beartooth Mountains, a block of Precambrian and younger rocks about 25 miles wide and 75 miles long in northwestern Wyoming, were formed primarily by vertical uplift. Uplift along the Beartooth fault, which forms the south margin of the block, was as much as 20,000 feet and occurred mostly during Eocene time. Pierce reports that farther east [28] near-surface anticlines grade downward into monoclines at depths of 5,000 to 7,000 feet, and may pass into faults at greater depths.

Base of Madison Limestone contains late Devonian fossils

Regional stratigraphic studies by C. A. Sandberg, in collaboration with J. F. Murphy, J. W. Huddle, and Gilbert Klapper, indicate that at some localities in west-central and north-central Wyoming as much as 20 feet of crinoidal and coralline dolomite at the base of the Madison Limestone is of very late Devonian age. It is overlain by Mississippian beds older than those in the Madison Limestone in Montana.

Stratigraphic units traced from Wind River Mountains to Owl Creek and Bighorn Mountains

Stratigraphic units in the Wind River Mountains of west-central Wyoming have been traced by W. J. Sando into the eastern Owl Creek and Bighorn Mountains by means of 13 detailed stratigraphic sections. The *Spirifer* cf. *S. madisonensis* zone in the upper half of the Madison Limestone forms a widespread, readily recognizable unit. A breccia unit, thought to represent a leached evaporite interval, occurs immediately below the brachiopod zone in all the sections.

[28] W. G. Pierce, in press, Geologic map of the Cody quadrangle, Park County, Wyoming: U.S. Geol. Survey Quad. Map GQ–542.

Twenty-three index ammonite zones in Cretaceous rocks

Twenty-three index ammonite zones are recognized in Cretaceous marine rocks in Wyoming and adjacent areas by J. R. Gill. The configuration of the strandline patterns for each zone and the alternation of transgressive and regressive deposits appear to be the result of local crustal instability rather than eustatic fluctuation of sea level or epeirogenic movements.

Three pre-Bull Lake glaciations in northwestern Fremont County

Glacial deposits formerly grouped as Buffalo Till in the Kisinger Lakes and Fish Lake quadrangles have been subdivided into 3 units by R. L. Rohrer. They are believed to represent 3 pre-Bull Lake glaciations and are the first such 3-fold subdivisions recognized outside the type area. The oldest unit has detritus derived from the Absaroka Mountains and Lava Mountain; the detritus of the intermediate unit was derived from the Wind River Mountains, probably south of Union Peak, and also from the Absaroka Mountains and Lava Mountain; the most recent deposit, an end moraine, is composed almost entirely of detritus from Lava Mountain.

Tepee Trail and Wiggins Formations partly correlative

K. B. Ketner and W. R. Keefer indicate that the lower Tertiary Tepee Trail and Wiggins Formations are partly correlative in the southern Absaroka Mountains of Fremont County. Local relief on the contact between these formations is more than 1,500 feet and seems to be the result of intertonguing rather than of structural complications or unconformity. Fossil tree leaves found in the Wiggins and identified by H. D. MacGinitie date the lower part of the Wiggins and the correlative upper part of the Tepee Trail as early Oligocene.

Possible origin of uranium deposits in Gas Hills and Crooks Gap, central Wyoming

Pyrite and high-sulfur oil from Paleozoic and Mesozoic rocks were introduced into Miocene and older Tertiary rocks during the post-Miocene stage of maximum sedimentary load according to J. D. Love. Love believes that the emplacement of the oil was triggered by epeirogenic uplift and collapse of the Granite Mountains. The pyrite created a favorable environment for uranium that was subsequently leached from the overlying Pliocene Moonstone Formation. The uraniferous water was trapped in local petroliferous and highly pyritic environments by Pleistocene warping and faulting.

Gravity profiles suggest possible oil and gas reservoirs in central Wyoming

Gravity profiles between the Granite Mountains and Great Divide Basin suggest that a deep-seated, north-dipping thrust fault may be present beneath Crooks Mountain, according to J. E. Case and W. R. Keefer (p. C120–C128). If such a thrust fault is present, Paleozoic and Mesozoic rocks beneath the thrust may be potential oil and gas reservoirs.

New Fork and Cathedral Bluffs Tongues of Wasatch Formation

W. C. Culbertson has concluded that the New Fork Tongue of the Eocene Wasatch Formation in the northwestern part of the Green River Basin in Lincoln County is neither a rock-stratigraphic nor a time equivalent of the Cathedral Bluffs Tongue of the Wasatch in the Great Divide and Washakie Basins. The New Fork Tongue is a predominantly fluviatile sequence that can be traced basinward into a sandstone body in the middle of the lacustrine Tipton Shale Member of the Green River Formation. The Cathedral Bluffs Tongue is the fluviatile equivalent of the upper three-fourths of the predominantly lacustrine Wilkins Peak Member of the Green River Formation.

Ferris Mountains partly buried in Pliocene time

The Ogallala Formation, of Miocene and Pliocene age, has been found in Carbon County by M. W. Reynolds on the southwest flank of the Ferris Mountains in the Muddy Gap and Lamont quadrangles. This indicates that the west end of the Ferris Mountains was at least partly buried by sediments in Pliocene time, and suggests that much of the present drainage pattern in the area is superposed from a cover of Tertiary rocks.

Volcanism more prevalent in Miocene than in Oligocene or Pliocene

Results of regional mapping of Tertiary rocks from central Wyoming to northwestern Nebraska by N. M. Denson and extensive petrographic work by Yoshiaki Sato on heavy-mineral separates from the White River, Arikaree, and Ogallala Formations indicate that, in the areas studied, volcanism was far more prevalent in the Miocene than in either the Oligocene or Pliocene. The paucity of volcanic minerals and the sudden abundance of plutonic and metamorphic components in the heavy-mineral suites from the Ogallala Formation (upper Miocene and Pliocene) indicates tectonism of regional significance during late Miocene and early Pliocene time.

Late Cretaceous unconformity

According to J. R. Gill and W. A. Cobban (p. B20–B27), the unconformity below the Teapot Sandstone Member of the Mesaverde Formation described by M. W. Reynolds (p. B69–B76) in the Lamont-Bairoil area, is present throughout much of Wyoming. Some oil and gas fields in western Wyoming are related to this unconformity.

SOUTHERN ROCKY MOUNTAINS AND PLAINS

NEBRASKA AND WYOMING

Permian evaporites in the Alliance basin

The paleogeographic setting of Permian evaporites, including halite, in the Alliance basin of western Nebraska and adjacent Wyoming has been described by E. K. Maughan (r0770). During Permian time the area probably was subequatorial with a warm dry climate. Marine waters from the Phosphoria sea to the west entered the basin area through an east-west seaway in southern Wyoming, and carbonate sediments, fine-grained red beds, and evaporites were deposited generally from west to east. Evaporite deposition resulted from a favorable combination of climate and geography.

COLORADO

Precambrian history in Needle Mountains, Colo.

A restudy of the Precambrian rocks of the Needle Mountains and vicinity in southeastern Colorado by Fred Barker has led to revisions in the Precambrian history of the area. Deposition, first of the Vallecito Conglomerate and then of Irving Greenstone, was followed by tight folding, metamorphism to high rank, and intrusion of the synkinematic Twilight Granite and postkinematic Tenmile Granite. Deep erosion exposed the plutonic rocks before the sedimentary rocks of the Uncompahgre Formation were deposited. These sedimentary rocks in turn were folded isoclinally, metamorphosed to quartzite, slate, and schist, and intruded by the Eolus Granite. A second period of erosion cut deeply into these units before Cambrian and younger strata were deposited.

Metamorphism in central Front Range, Colo.

Petrographic studies by D. M. Sheridan of Precambrian pelitic gneisses in the Squaw Pass and Evergreen quadrangles, Front Range, Colo., have shown that the stable pair microcline-sillimanite in thick units of biotite gneiss is common throughout the area and that the highest metamorphic grade attained is qualitatively analogous to that of the upper sillimanite zone of New England. The presence of late muscovite replacing both sillimanite and microcline is interpreted to be evidence for mild retrograde metamorphism. Noteworthy amounts of muscovite in these rocks, of an apparently earlier generation than the retrograde grains, seem anomolous. However, as Guidotti[29] has demonstrated in Maine, the occurrence of muscovite in rocks above the sillimanite–potash feldspar isograd need not be evidence of disequilibrium, the association being simply a function of the chemical composition of the rocks.

Granodiorite reconstituted by intense deformation

C. T. Wrucke determined, from a study of a 75-foot-wide shear zone in the Precambrian Boulder Creek Granodiorite in the Boulder quadrangle of north-central Colorado, that during shearing the rock was thoroughly reconstituted mineralogically without producing significant changes in its chemical composition. The central part of the zone now is a hornblende-quartz-feldspar gneiss that resembles some metasedimentary gneisses of the Front Range.

Geology and geochemistry of Redskin Granite

Three distinct periods of igneous activity are recognized by C. C. Hawley, Claude Huffman, Jr., J. C. Hamilton, and L. F. Rader, Jr. (p. C138–C147) in the Precambrian terrane of the Lake George area of eastern Park County, Colo. The Redskin Granite is moderately enriched in tin, lithium, rubidium, and beryllium relative to the somewhat older and coarser grained rocks of the adjacent Pikes Peak Granite. The amount of enrichment is considered moderate because some of the "tin granites" of the world contain more tin, lithium, and beryllium, and classic rapakivi granite and some other acid granite contain much more rubidium.

New salt diapir recognized

The Cattle Creek anticline, 7 miles south of Glenwood Springs, Garfield County, Colo., is determined to be a salt diapir by W. W. Mallory (p. B12–B15). Halite penetrated by a well in the central part of the structure is at least 935 feet thick. It is postulated that halite flowage commenced when overburden was removed from the crest of a preexisting anticline. If structural closure is adequate beneath the evaporites, oil and gas may be present in strata of Cambrian, Ordovician, Devonian, or Mississippian age. The great thickness of halite suggests that potash salts may occur in the Eagle Valley Evaporite (Pennsylvanian and Permian).

[29] C. V. Guidotti, 1963, Metamorphism of the pelitic schists in the Bryant Pond quadrangle, Maine: Am. Mineralogist, v. 48, p. 772–791.

Eolian member of Maroon Formation

Work by V. L. Freeman along the Fryingpan River in the Ruedi quadrangle of western Colorado disclosed a readily mappable member of the Pennsylvanian and Permian Maroon Formation. This unnamed member is an approximately 300-foot-thick sandstone unit characterized by large-scale sweeping crossbedding, and lies about 2,500 feet below the top of the Maroon, which in this area may exceed 10,000 feet in thickness. The sorting and crossbedding of the unnamed member suggest an eolian origin which, if supported by continuing work, provides new evidence for interpretation of the paleogeography of the region during Maroon time.

Tertiary stratigraphy of Rabbit Ears Range, north-central Colorado

G. A. Izett (p. B42–B46), working in the Hot Sulphur Springs quadrangle, Middle Park, Colo., has described the middle and late Tertiary extrusive volcanic rocks of the Rabbit Ears Range. The Rabbit Ears Volcanics of Oligocene and Miocene(?) age lie unconformably on the Middle Park Formation of Late Cretaceous and early Tertiary ages. The Rabbit Ears Volcanics contain a lower unit of trachybasalt lavas named the Pete Gulch Member, 0 to 200 feet thick, and a thick upper unit of layered tuff, breccia, and lavas of silicic to intermediate composition. These volcanic rocks are overlain locally by tuffaceous basin-fill sedimentary rocks of the Miocene Troublesome Formation or by Pliocene(?) olivine-bearing basalt flows, named the Grouse Mountain Basalt.

Faults near Aspen, Colo.

Mapping by Bruce Bryant in the Lenado mining district in the northeast corner of the Aspen quadrangle of Pitkin County, Colo., and in adjacent quadrangles shows that some cross faults, such as the Lenado fault, which cut the Precambrian and lower Paleozoic rocks at the margin of the Sawatch Range become parallel with the bedding in the Carboniferous rocks. This supports the general concept of bedding-plane faults in the Aspen district as advanced by Spurr.[30]

In the Elk Mountains, 9 miles south of Aspen, Colo., a block of structurally complex rocks underlies a block of structurally simple rocks. According to Bruce Bryant (p. D1–D8) the rock types and the structural features here indicate that the structurally complex rocks may be in a window in the Elk Range thrust sheet.

[30] J. E. Spurr, 1898, Geology of the Aspen mining district, Colorado: U.S. Geol. Survey Mon. 31, 260 p. and atlas.

Laramide thrust fault north of Steamboat Springs, Colo.

A Laramide thrust fault has been traced by George Snyder for 18 miles along the western front of the Park Range, north of Steamboat Springs in northwestern Colorado. Generally, the thrust brings the Cretaceous Niobara Formation in contact with Precambrian crystalline rocks, but locally most of the section from the Goose Egg Formation of Permian and Triassic age through the Niobrara is exposed in both plates of the thrust. Contrary to previous mapping which showed the Triassic Chugwater Formation in thrust contact with the Precambrian north and east of Clark, the contact of the Chugwater or Goose Egg with Precambrian rocks is believed to be a stratigraphic unconformity; the thrust as now recognized lies west of this contact. The thrust is believed to dip west where the upper-plate rocks are in normal sequence and to dip east by overturning where the upper-plate rocks are overturned. Near the south end of Copper Ridge, north of Steamboat Springs, the thrust is truncated by a post-Miocene normal fault with more than 1,200 feet of displacement.

Origin of dunes at Great Sand Dunes National Monument, Colo.

The source of the sand forming the large spectacular dunes at Great Sand Dunes National Monument of south-central Colorado has been studied by R. B. Johnson. The ultimate source of the sand appears to be within the drainage area of the upper Rio Grande, in the volcanic terrane of the San Juan Mountains to the west. Natural levees which were built along a now-abandoned stretch of the Rio Grande from near Alamosa to the San Luis Lakes—about 8 miles southwest of the Monument—form sinuous low mounds and hummocks. Sand from the levees was blown into a now-stabilized group of dunes near the San Luis Lakes. Large blowouts in the stabilized dunes are the immediate source of sand forming the active dunes in the Monument.

Northward extension of Nussbaum Alluvium in Denver basin, Colorado

P. E. Soister has mapped an extensive deposit of unfossiliferous arkosic sand and gravel as the Nussbaum Alluvium of earliest Pleistocene(?) age in the Corral Bluffs quadrangle a few miles east of Colorado Springs, Colo. The deposit, generally 100 to 150 feet thick, caps a high-level surface which slopes to the south and southeast. This surface is about 1 to 3 miles wide, more than 20 miles long, and truncates the Dawson, Laramie, Fox Hills, and Pierre Formations. The lithology and geomorphic occurrence of the deposit are quite similar to those same features of the Nussbaum at its type locality. The highest of numerous similar deposits to the north, northwest, and northeast of Corral Bluffs is generally a few hundred feet below the South Platte–Arkansas River divide. The Nussbaum Alluvium, post-Nussbaum alluvium of Pleistocene age, and eolian sand of Recent age make up most of the deposits between the Arkansas River and Big Sandy Creek that are shown as Ogallala Formation of Pliocene age on the State geologic map [31] and as Miocene deposits on the new geologic map of North America.[32]

Aeromagnetic anomalies as ore guides, Sawatch Range, Colo.

Analysis by J. E. Case of aeromagnetic anomalies over the Tertiary Mount Princeton batholith in the Garfield quadrangle of central Colorado indicates that portions of the batholith of quartz monzonitic to granitic rock cause aeromagnetic highs. Thus, in places these rocks contain moderate to abundant amounts of magnetite. Prominent aeromagnetic lows occur over parts of the batholith, however, and coincide with zones of altered porphyry and with some of the major mining districts, suggesting that original magnetite at these places was altered to relatively nonmagnetic iron minerals. The close correlation between the magnetic lows and the areas of alteration and mineral deposits indicates that the magnetic lows should be considered as guides to exploration for possible mineralized areas.

New data on Ilse fault zone of central Wet Mountains

Mapping by Q. D. Singewald in the central Wet Mountains of south-central Colorado has relocated part of the Ilse fault zone (p. C20–C24). Also, several strong radioactive anomalies were discovered north of previously reported mineralization.

Study of Twin Lakes batholith

H. G. Wilshire, J. T. O'Connor, and G. A. Swann studied and mapped the geology of the Twin Lakes batholith, in Lake and Chaffee Counties in central Colorado. The northern part of the batholith is composed of porphyritic quartz monzonite that was emplaced in Precambrian metamorphic and igneous rocks. An abundance of large orthoclase phenocrysts, commonly 3 to 5 inches long, serves to distinguish this rock from other granitic intrusions in the region. In marginal parts of the batholith, orthoclase phenocrysts are commonly concentrated in lenses; thin layers enriched in mafic minerals occur in the same areas

[31] W. S. Burbank, T. S. Lovering, E. N. Goddard, and E. B. Eckel, 1935 (reprinted 1959), Geologic map of Colorado: U.S. Geol. Survey, scale 1:500,000.

[32] E. N. Goddard, chm., North American Geologic Map Committee, 1965, Geologic map of North America: U.S. Geol. Survey, scale 1:5,000,000.

and define a locally pronounced flow foliation. The batholith is cut by north- and northeast-trending faults, many of which are occupied by rhyolite dikes; other minor intrusions within the Twin Lakes batholith include irregular masses of fine-grained granite, and lamprophyric dikes.

COLORADO PLATEAU

UTAH

Inoceramus-bearing bed in Straight Cliffs Formation

W. A. Cobban has identified the pelecypod *Inoceramus involutus* Sowerby among fossils submitted by H. D. Zeller from the Canaan Creek quadrangle just south of Escalante, in southern Utah, on the Kaiparowits Plateau. This inoceramid, which is a guide fossil to rocks of middle Niobrara age (Late Cretaceous), occurs near the top of a 100-foot-thick marine sandstone bed about 450 feet above the base of the Straight Cliffs Formation.

COLORADO

Boundary between Moenkopi and Park City Formations

The contact between the Moenkopi Formation (Triassic) and the Park City Formation (Permian) along the south flank of the Uinta Mountains near the Colorado-Utah State line has been shifted upward by E. M. Schell and E. L. Yochelson (p. D64–D68) to include in the Park City 25 to 67 feet of "tawny beds." The "tawny beds," largely silty limestone and dolomite, also contain cherty layers and phosphatic dolomite and contain a marine fauna of Permian age. These beds, which were formerly included in the Moenkopi Formation, correlate with the upper unit of the Franson Member of the Park City Formation in the Ashley Creek–Brush Creek area.

Fossil vertebrates in Cutler Formation

Fossil vertebrates have been collected and described by G. E. Lewis (r1555), U.S. Geological Survey, and P. P. Vaughn, University of California, Los Angeles, from the upper quarter of the undivided Cutler Formation in the Placerville area of southwestern Colorado. The fauna is very similar to that collected from the Halgaito Tongue of the Cutler Formation, which is the lowermost of four members in the Mexican Hat area of southeastern Utah.[33] The faunas from these two areas are of early Permian (Wolfcamp) age. It is possible therefore that all of the Cutler at Placerville was deposited during Wolfcamp time. The discovery and identification in the Placerville collections of bones of the reptile *Cutleria wilmarthi* Lewis and Vaughn represent the first haptodontine pelycosaur to be described from North America. The typical closely comparable haptodontine pelycosaurs have long been known in the Autunian of France and the lower Rotliegende of Germany (Early Permian-Sakmarian).

Age of basalt cap on Grand Mesa

A whole-rock potassium-argon determination by R. F. Marvin, H. H. Mehnert, and W. M. Mountjoy, of the basalt on top of Grand Mesa, Mesa County, Colo., yielded an early Pliocene age of 9.7±0.5 million years. The basalt was formerly dated only as post-Green River (post-middle Eocene). The analyzed specimen was taken by J. R. Donnell and Warren Yeend from about the middle of a series of flows aggregating about 800 feet in thickness. Since the outpouring of the basalt, the Colorado River has lowered its channel nearly 6,000 feet, which is at the rate of 6 inches each thousand years.

Unaweep Canyon carved by Gunnison River

Newly found exposures of both ancient river gravels and fanglomerates have led F. W. Cater (p. C86–C92) to conclude that Unaweep Canyon, a spectacular wind gap across the Uncompahgre Plateau in southwestern Colorado, was carved by the Gunnison River and abandoned in late Pliocene time as a consequence of the rise of the modern Uncompahgre uplift. Structural relief of the uplift, which probably began to rise in middle or late Pliocene time, totals more than 2,000 feet, of which 1,300 to 1,400 feet are believed to have occurred after abandonment of Unaweep Canyon.

Stream piracy on the Gunnison

Exhumation of the Gunnison uplift on the eastern edge of the Colorado Plateau in late Cenozoic time was accompanied by significant drainage adjustments, according to W. R. Hansen. Tributaries such as Grizzly Gulch and Crystal Creek, that flowed to the Gunnison River across the hard-rock core of the uplift, were captured by more rapidly eroding subsequent streams such as Iron Creek that flowed to the Smith Fork through soft rocks. The former courses of the streams are indicated by distinctive gravel deposits: Grizzly Gulch formerly drained an area of volcanic rocks, and Crystal Creek an area of hypabyssal porphyries. Smith Fork still heads in the West Elk Mountains and accordingly carries fragments of porphyry in its gravels. Its capture by tributaries of North Fork in the near future is probable. Similar stream adjustments have also modified drainage patterns on the southwest side of the Gunnison uplift.

[33] P. P. Vaughn, 1962, Vertebrates from the Halgaito Tongue of the Cutler Formation, Permian of San Juan County, Utah: Jour. Paleontology, v. 36, no. 3, p. 529–539.

NEW MEXICO

Ojo Alamo redefined

The Ojo Alamo Sandstone and related beds at the type section in the central part of the San Juan basin of New Mexico have been redefined and the problem of the Cretaceous-Tertiary boundary amended by E. H. Baltz, S. R. Ash, and R. Y. Anderson.[34] They report that the Ojo Alamo Sandstone as previously used by C. M. Bauer [35] includes rocks of Montana (Late Cretaceous) age and rocks of early Paleocene age that are separated by a widespread erosional unconformity. Rocks of latest Cretaceous (Lance) age, including those that elsewhere contain *Triceratops* bones, are missing. The name Ojo Alamo is now restricted to the upper conglomeratic sandstone of Bauer's Ojo Alamo. The underlying thin beds of conglomerate and shale that contain dinosaur bones are named the Naashoibito Member and are assigned to the Kirtland Shale. Inasmuch as the restricted Ojo Alamo intertongues with beds of the Nacimiento Formation that contain good assemblages of pollen as well as the Puerco fauna—both of Tertiary age—the unconformity at the type locality there marks the boundary between the Cretaceous and Tertiary systems.

Laccoliths of Ortiz Mountains, N. Mex.

Brief reconnaissance by D. G. Wyant indicates that the Ortiz Mountains, between Santa Fe and Albuquerque, N. Mex., resemble laccolithic mountain groups of the Colorado Plateau in morphology and in similarity of rock types. In the northern part of the mountains, calc-alkalic porphyries in the general range of monzonite occur as large sills, dikes, probably at least 3 laccoliths, and at least 1 central stock. The, shatter zone of the central stock contains lode deposits of gold, scheelite, and minor common sulfides.

ARIZONA

Age range of Supai Formation

In the eastern part of the Grand Canyon, Ariz., the Supai Formation (Pennsylvanian and Permian) is composed of nonfossiliferous and, therefore, poorly dated red beds of continental origin. The sequence of rocks includes many beds of continental sandstone and thin persistent conglomerate beds. These continental rocks intertongue and intergrade westward into fossiliferous beds in the western part of the Grand Canyon. Faunas collected by E. D. McKee from measured sections of these fossiliferous beds have been studied by L. G. Henbest (smaller Foraminifera); R. C. Douglass (fusulinids); W. J. Sando (corals); R. E. Grant, Jr. (brachiopods); and D. H. Dunkle (fish), who have recognized faunal zones characteristic of Morrow, Des Moines, Virgil(?), and Wolfcamp age of the midcontinent. Tracing of the key conglomerate beds of the continental sequence into the fossiliferous marine rocks enables subdivision of the nonmarine Supai and more closely establishes its age range as extending from Early Pennsylvanian to Early Permian.

[34] U.S. Geological Survey, 1964, Geological Survey research 1964, chapter A: U.S. Geol. Survey Prof. Paper 501–A, p. A100.

[35] C. M. Bauer, 1916, Stratigraphy of the Chaco River valley: U.S. Geol. Survey Prof. Paper 98–P, p. 275–276.

BASIN AND RANGE REGION

REGIONAL STUDIES

Provenance of Ordovician quartzites

Stratigraphic studies by K. B. Ketner (p. C54–C60) have shown that Ordovician quartzites of the Cordilleran geosyncline were derived from sedimentary terranes composed at least partly of quartz sandstone. The compositional and textural maturity of the quartzites precludes a sizable contribution of material from igneous or metamorphic terranes. The quartzites of the eugeosyncline are lithically similar to those of the miogeosyncline, but they are slightly coarser grained and not quite so well sorted. Stratigraphic and textural relations indicate that the quartzites of the miogeosyncline were derived from the eastern side of the geosyncline, and that the quartzites of the eugeosyncline were derived from the west side.

NEVADA

Localization of mining districts in Toquima Range

In the Toquima Range in northern Nye County, the Belmont, Barcelona, and Round Mountain mining districts, which have yielded gold, silver, mercury, and tungsten, lie along the periphery of a large elongate granitic pluton. Earlier workers believed that the pluton was discordant with the Paleozoic country rocks, but recent mapping by F. J. Kleinhampl and J. I. Ziony shows that the intrusive margin and the attitude of the surrounding Cambrian and Ordovician rocks are generally concordant, and that the intrusive may have domed the sedimentary cover. Fractures which provided channelways for ore solutions probably were concentrated near the axis of the dome and may account for the localization of the three districts along or near the axis.

Isoclinal folds in Ruby Mountains

C. R. Willden and R. W. Kistler report that field observations and structural analysis of Paleozoic rocks of the carbonate (miogeosynclinal) assemblage in the southern Ruby Mountains of northeastern Nevada show that the lower and upper parts of the section differ strongly in structural style. Cambrian and Ordovician rocks show overturned folds that are similar to those found in the siliceous (eugeosynclinal) assemblage of the Antler orogenic belt. Such recumbent folds are missing in Devonian and younger rocks wherever examined thus far. Preliminary Rb-Sr whole-rock dating in the Ruby Range suggests that intrusion of pegmatitic granite occurred in the Devonian, in addition to an intrusive epoch in the Late Jurassic. The age data, in combination with the structural observations, suggest orogenesis in the region during Devonian time.

Thrust fault in Robinson (Ely) mining district

Geologic mapping by A. L. Brokaw in the Ruth, Ely, and Reipetown quadrangles in the Egan Range of east-central Nevada has delineated a major thrust fault in the Chainman Shale and Ely Limestone. Segments of this fault occur throughout the main mining district, and in several areas it has influenced the emplacement and form of the sill-like monzonitic intrusive bodies. Potassium-argon analyses on hornblende and biotite from altered and unaltered intrusive rocks strongly suggest an Early Cretaceous age. The thrust faulting therefore is probably no younger than Early Cretaceous and may be considerably older.

Faults in southern Snake Range

Analysis of structures in the upper part of a regional decollement in the southern Snake Range, eastern Nevada, by D. H. Whitebread reveals numerous faults which terminate at the thrust plane. Of special significance among these are several east-dipping low-angle faults that have undergone normal displacements of more than 1 mile each. The faults resulted in eastward distention and stratigraphic attenuation, and the fault pattern strongly suggests that they resulted from gravitative forces.

New formation in northern Elko County

R. R. Coats, mapping in the Owyhee and Mountain City quadrangles, Elko County, Nev., has found additional exposures of a recently discovered formation that is younger than the Ordovician Valmy Formation and older than the Pennsylvanian(?) or Permian(?) Banner Limestone of Granger and others. The unnamed formation is largely clastic, ranging from siltstone to coarse conglomerate with fragments largely derived from the Valmy Formation. It occurs as fault slices or infolded masses in the Valmy, and is overlain in thrust contact by the Valmy along a newly discovered thrust. Locally it is overlain unconformably by the Banner Limestone, but the relation of the Banner to the thrust cannot be determined. The age of the unnamed formation is not known from fossils. Field relations strongly suggest that the geologic history of the area includes two orogenic episodes in post-Valmy and pre-Banner time.

Thrust faults in northern Sonoma Range

Detailed mapping of the complex structure in the northern Sonoma Range of northern Nevada by James Gilluly has shown that many of the thrusts are folded, and that several thrust faults mapped during reconnaissance studies by earlier workers are actually different segments of the same fault. All the structures are explicable by only two major thrusts, both overfolded toward the west. Since both these thrusts involve Triassic rocks, there is no direct nor any compelling indirect evidence of the Late Devonian Antler orogeny in the area, as had been earlier postulated.

History of volcanism in Cactus Range

Recent geologic mapping in the Cactus Range, Nye County, Nev., by R. E. Anderson and E. B. Ekren indicates that the range is a complex volcanic center from which two major ash-flow tuff sheets were extruded in Miocene time. The tuffs of Antelope Springs were succeeded by the tuffs of White Blotch Spring, but eruption of the 2 units was separated by a period of intense deformation, probably related to caldera collapse, and by deposition of as much as 800 feet of lacustrine sedimentary rocks. After extrusion of the tuffs of White Blotch Spring another large caldera developed. A prolonged period of vertical uplift of the entire caldera followed, accompanied by emplacement of a complex system of intrusive masses. The Mount Helen volcanic center, a few miles south of the Cactus Range, probably was the source for the upper Miocene tuffs of Tolicha Peak as well as thick widespread lavas of quartz latite composition. Eruption of the tuffs of Tolicha Peak resulted in collapse of an area about 4 miles in diameter.

Volcanic sequence in northern White Pine County

R. K. Hose and M. C. Blake have shown by reconnaissance mapping that the volcanic sequence of northern White Pine County consists of three major units: an oldest series ranging from pyroxene latite to biotite rhyolite, an intermediate prominent white tuff or pumice breccia, and an upper series of platy hornblende latite. An ash-flow tuff of quartz latite locally marks the base of the sequence.

UTAH

Inferred thrust fault in central Utah

Regional mapping of the Cherry Creek quadrangle and adjacent areas by H. T. Morris has indicated the existence of a totally concealed major thrust fault in central Utah that has been named the Tintic Valley thrust (R. J. Roberts and others, r1594). This thrust apparently brings the West Tintic sequence, characterized by Middle Ordovician quartzite and shale, and a great thickness of Upper Ordovician, Silurian, and Devonian carbonate rocks over, or adjacent to, the East Tintic sequence that has no Middle Ordovician rocks and in which Upper Ordovician, Silurian, and Devonian rocks are both thinner and of substantially different lithologic character. Definitive evidence for the existence of the Tintic Valley thrust will probably come only from deep drill holes.

Late Precambrian stratigraphic section near Huntsville

Detailed stratigraphy of approximately 11,000 feet of younger Precambrian and Cambrian(?) rocks resting on the Willard thrust has been developed during geologic mapping of the Browns Hole quadrangle near Huntsville, northern Utah, by M. D. Crittenden, Jr. The lowest units are argillite and fine-grained arkose whose base is not exposed. These are overlain conformably by: thin conglomerates containing clasts of fuchsite-bearing quartzite like that found in Raft River Range; a thin buff-weathering laminated dolomite; argillites containing thin lenticular beds of limestone; a thick white quartzite; thin purple and olive-drab argillite; a thick unit of purple quartzite; and a thin basaltic flow. The basalt is overlain by 1,000 feet of arkosic quartzite and shale, grading up through a 100-foot zone of cobble conglomerate into 3,400 feet of pale-tan quartzite assigned to the Brigham Quartzite (restricted) and presumed to be Cambrian in age. The whole sequence resembles most closely the sequence of Precambrian rocks near Pocatello, Idaho.

Intersecting breccia zones localize ore bodies in Stockton district

Fieldwork in the Stockton district, Tooele County, Utah, by W. J. Moore, G. C. Curtin, E. W. Tooker, and R. J. Roberts (p. C197–C205) has shown that the base-metal ore bodies are localized at the intersections of northeast-trending breccia zones and thin argillaceous limestones in the Bingham sequence of the Pennsylvanian and Permian Oquirrh Formation. Spectrographic analyses of about 1,000 bedrock and gossan samples collected in the vicinity of these ore bodies indicate a distribution of metals that is zonally related to a northwest-trending intrusive center of Tertiary age. (See also section on geochemical prospecting under "Techniques of Mineral Exploration.")

Thick Devonian section subdivided in Confusion Range

R. K. Hose (p. B36–B41) has subdivided in the Confusion Range of west-central Utah a section of Devonian strata, more than a mile thick, into four formations. In ascending order they are the Sevy Dolomite, Simonson Dolomite, Guilmette Formation, and Pilot Shale. The lower part of the Pilot Shale has Devonian fossils, but its upper part, at least locally, contains a fauna of Early Mississippian age.

Pennsylvanian sequence in northeastern Utah

A previously unreported complete section of Pennsylvanian rocks examined by T. E. Mullens in the Causey Dam quadrangle, northeastern Utah, provides new data on the regional extent and significance of the Willard thrust fault. The section is slightly more than 1,000 feet thick, and it includes approximately 425 feet of limestone tentatively assigned to the Round Valley Limestone and 600 feet of sandy dolomite and limy quartzite assigned to the Wells Formation. These units overlie a thick section of older Paleozoic rocks which in turn rests on a thick section of quartzite and shale of late Precambrian age. Both the thickness and the character of Pennsylvanian rocks in the Causey Dam quadrangle contrast strongly with those of rocks of the same age exposed 15 miles south in Weber Canyon. Here 3,500 feet of Pennsylvanian rocks overlies a thin section of lower Paleozoic rocks which in turn rests on crystalline Precambrian basement, the Farmington Canyon complex. The thin Pennsylvanian sequence provides further stratigraphic evidence that rocks in the Causey Dam and Browns Hole quadrangles are in the upper plate of the Willard thrust fault.

ARIZONA

Source of ground water in Tucson basin

Geologic studies in the northern half of the Tucson basin by E. F. Pashley, Jr., indicate that undeformed sand and gravel of probable late Pliocene and early Pleistocene age are the principal source of ground water in the basin. Surface mapping and subsurface studies indicate that the sand and gravel were deposited as alluvial fans that extended from the mouths of canyons along the fronts of the Santa Catalina, Tangue Verde, and Rincon Mountains to the center of the basin. Erosion has since removed these fan deposits from wide areas adjacent to the mountains and has exposed the faulted and tilted Tertiary sediments and bedrock pediments upon which the fans were deposited.

Age of stock emplacement in southeastern Arizona

Continuing investigations by S. C. Creasey of the isotopic ages of stocks spatially associated with base-metal deposits in southeastern Arizona have added significant data on their emplacement history and origin. In the Globe-Miami district at least five petrographically distinct rock types occur as stocks and small irregularly shaped intrusive masses. The stocks seem to be of three ages: 500–600 million years, 113 m.y., and 55–65 m.y. At least one of the oldest stocks is chemically and mineralogically similar to the youngest, suggesting that the process, or processes, that generated the stocks was periodically active since late Precambrian time. The recognition of stocks of different ages raises the possibility of ore deposits of different ages in the same district.

In districts that contain stocks of different compositions but of the same general age, the stocks with the most normative plagioclase and the highest mafic content (closest to quartz diorite) are the oldest, and the stocks highest in sialic constituents (alkali feldspar and quartz) are the youngest. This strongly suggests that within individual districts such stocks are the products of differentiation from some magma chamber well below the present level of observation.

Precambrian folded unconformity in central Arizona

P. M. Blacet reports (p. B1–B5) that the Alder Group of the older Precambrian Yavapai Series and the underlying Brady Butte Granodiorite are separated by an unconformity that has been folded. The Brady Butte Granodiorite predates the Mazatzal revolution, a widespread regional metamorphic and plutonic episode during which the overlying Alder Group was metamorphosed, and therefore represents a plutonic event older than any previously recognized in Arizona.

Exotic blocks and breccias in Mesozoic rocks

Mapping by F. S. Simons and others (p. D12–D22) in southeastern Arizona has delineated sizable exotic blocks or coarse sedimentary breccias of older rocks in thick sequences of Mesozoic volcanic and sedimentary rocks. The large blocks are believed to have been emplaced by dragging or rafting by lava flows, by gravity sliding, or by transport in ash flows.

CALIFORNIA

Major thrust fault in eastern Inyo County

A major thrust fault has been mapped by J. H. Stewart, D. C. Ross, C. A. Nelson, and B. C. Burchfiel (p. D23–D34) in the eastern part of Inyo County, Calif. The fault, named the Last Chance thrust, has been traced throughout an area of more than 400 square miles, and probably extends in the subsurface under most of the northern Inyo Mountains and southern White Mountains. Upper Precambrian, Cambrian, and Ordovician formations that form the sole of the upper plate are thrust eastward over Silurian and Mississippian formations. The net slip of the thrust is believed to be at least 20 miles.

Stratigraphy in southern Great Basin of California and Nevada

J. H. Stewart has described the stratigraphic relationships of Lower Cambrian and some Precambrian rocks of the Spring Mountains-Death Valley region of Nevada and California with equivalent rocks of the White-Inyo Mountains region of California (p. C66–C72). Changes in the stratigraphic section northwestward from the Spring Mountains-Death Valley area to the White-Inyo Mountains region include an increase in its thickness and lime content and decrease in the grain size of the clastic rocks.

Geology of Slate Range

A reconnaissance geologic and gravity map of the Slate Range, San Bernardino and Inyo Counties, by G. I. Smith, B. W. Troxel, C. H. Gray, and R. E. von Huene, has permitted identification of four west-dipping low-angle faults that involve rocks mapped as Precambrian(?), early Mesozoic, and late Mesozoic in age. The upper plate of one of these faults has been nearly removed by erosion, and anomalous topographic surfaces are interpreted as the exhumed sole of this fault. The present configuration of the low-angle fault surfaces seems partly due to warping, and this, in addition to evidence from the distribution of upper Cenozoic rocks, suggests that the present range is partly the product of warping during late Cenozoic time. However, displacements along three sets of high-angle faults within the range, and along the adjoining Garlock fault and Panamint Valley fault zones, have contributed to this relief. Fault scraps of late Pleistocene (Wisconsin) and Recent ages along the range boundaries indicate continuing tectonic activity into late Pleistocene time. Although the range represents an area of marked tectonism, and lies near the boundary between regions differing in terms of both structure and basement rocks, a gravity survey reveals no large deviation in the regional gravity field.

COLUMBIA PLATEAU AND SNAKE RIVER PLAIN

WASHINGTON

Yakima Basalt members are identifiable over much of southwestern Washington

Three members of the upper part of the Yakima Basalt of the Columbia River Group, which were traced eastward across southeastern Washington by K. L. Walters and J. W. Bingham,[36] have now been traced northward by Bingham across Adams County and into Lincoln County, indicating that the units are identifiable over much of southeastern Washington.

Cascade Mountains folded in middle Pleistocene time

A regional uplift and folding in the Cascade Range and the Columbia Plateaus took place in the middle Pleistocene, according to R. C. Newcomb. Gravel containing material derived from the northern Rocky Mountains appears to be restricted to post-middle Pleistocene deposits. This conclusion suggests that the Columbia River first occupied a course in the Dalles-Umatilla syncline during an episode of deformation in middle Pleistocene time.

OREGON

Pliocene deposits of northeastern Oregon once much thicker

During early Pliocene time, rocks of the Columbia River Group, the stratigraphically equivalent Strawberry Volcanics, and related fluviatile basin deposits probably attained a thickness of 8,000 feet or more over much of the present Canyon City quadrangle (1:250,000 scale), Oregon, according to T. P. Thayer and C. E. Brown (p. C73–C78; and Brown and Thayer, r2007). Much of the silicic fragmental material that probably formed most of the upper half of the regional volcanic blanket was removed before the Rattlesnake Formation was deposited in the John Day structural trough in middle Pliocene to Pleistocene time. At one time, siliceous fluviatile deposits equivalent to, and like, the Mascall Formation must have extended northward and many tens of miles over the present Columbia Plateau.

Recurrence of lithologically similar ash-flow tuffs in Danforth Formation

Multiplicity of lithologically similar ash-flow tuffs in the Danforth Formation is indicated by reconnaissance mapping in the southern and western parts of the Harney Basin, Oreg., by G. W. Walker, N. V. Peterson, and R. C. Greene during 1965, and, in prior years, by G. W. Walker and C. A. Repenning. The ash-flow field covers several thousands of square miles, mostly in northern Harney County. Stratigraphic relations and sparse vertebrate fossils suggest a Pliocene age for all the ash-flow tuffs, which is verified by several K-Ar age determinations indicating an age range from early Pliocene (9.7 million years) to late Pliocene (3.6 m.y.)

Dalles Formation of Oregon and Washington

Mapping by R. C. Newcomb indicates that the Dalles Formation, of Pliocene age, consists of a low cone of volcanic agglomerate deposited from debris flows that extended northward and northeastward from where Mount Hood now stands, and of an interfingering sedimentary facies of tuff, siltsone, and conglomerate brought from a source to the east by westward-flowing rivers (p. D59–D63). The sedimentary facies was mapped eastward to Rufus, Oreg., and similar deposits bearing other names were seen in an eastward reconnaissance to the vicinity of McKay Reservoir, Oreg., about 120 miles east of The Dalles.

IDAHO

Silicic volcanic rocks at moderate depth in Snake River Plain

The presence of silicic volcanic rocks at moderate depths along much of the southern limit of the National Reactor Testing Station is indicated by photoreconnaissance mapping and interpretation of geophysical and hydrologic data by G. H. Chase. The silicic volcanic rocks lie near the southwestern margin of a physiographic and geologic basin within the north-central part of the Snake River Plain.

Age of part of Snake River Group

A radiometric age of about 2.5 million years is reported by G. H. Chase for the upper 400 feet of basalt in the northern part of the National Reactor Testing Station. Potassium-argon ages for segments taken from near the top and bottom of a continuous core were in fairly close agreement. Except for about 0.9 foot of silty and sandy calcareous material, the core consisted entirely of basalt with little evidence of zones of deep weathering. Lithology and isotopic ages thus both indicate relatively rapid emplacement of this thickness of the basaltic lavas.

[36] U.S. Geological Survey, 1964, Geological Survey Research 1964, Chapter A: U.S. Geol. Survey Prof. Paper 501–A, p. A108–A109.

PACIFIC COAST REGION

WASHINGTON

Postglacial activity of Mount Rainier

During the course of mudflow studies in the vicinity of Mount Rainier, D. R. Crandell and D. R. Mullineaux have found that the history of the volcano is characterized by long periods of quiescence, interrupted by brief episodes of activity which produce lava flows, debris flows, and air-laid deposits of pumice and rock debris. At least four eruptions of pumice have occurred in approximately the last 10,000 years of postglacial time, the most recent about 2,000 years ago. The only known postglacial lava flows form the summit cone and are probably less than 5,000 years old. The present dormant state of the volcano does not reliably indicate that it is extinct, and if the pattern established in postglacial time continues, an eruption of one sort or another will occur on an average of once every 1,000 years.

Hazards caused by the eruption of lava and pumice are probably not great, but these eruptions may be accompanied by devastating floods and debris flows. Debris flows are a particular hazard because of a relatively high frequency of occurrence, an ability to travel long distances down valleys, and thicknesses of as much as 800 feet. More than 30 postglacial debris flows have moved down the floors of valleys that head at Mount Rainier. The destructive effects of similar debris flows in the future can be minimized by careful planning of land use on valley floors.

Cretaceous Xenoclasts in Eocene rocks

W. M. Cady, J. D. Obradovich, and M. L. Sorensen have found that in the Eocene Crescent Formation of the northeastern Olympic Mountains of Washington, exotic hornblende diorite blocks have a K-Ar age of 65±2.5 million years. These xenoclasts within the lavas and mudflow breccias of the Crescent are believed to have been derived from Upper Cretaceous rocks. The provenance of such exotic blocks, some of which are rounded and as much as 10 feet in diameter, is believed to be the Mesozoic metamorphic and granitic terrane of the Northern Cascade Mountains of Washington and the Coast Mountains of British Columbia.

Glacier Peak area explored

A roadless alpine area of northwest Washington near Glacier Peak has been explored geologically by D. F. Crowder, F. W. Cater, R. W. Tabor, and others. To help the ever-increasing numbers of visitors, the trails and routes of the areas as well as some of its geologic features have been described in a guidebook by Crowder and Tabor (r1663).

Possible Beltian rocks in northeastern Washington

Fieldwork on the Chewelah Mountain quadrangle in northeastern Washington by L. D. Clark and F. K. Miller has shown that five units compose a thick section of Precambrian argillite, quartzite, and dolomite which in aggregate represent the bulk of the sedimentary rocks in the quadrangle. The oldest of these units, the Togo Formation, comprises more than 8,000 feet of interbedded argillite and fine-grained quartzite. It may represent a transition between known Beltian rocks near Bead Lake, about 15 miles to the east, and the almost completely argillitic facies of the Togo Formation in the northeastern Washington magnesite belt 15 miles to the west. If this correlation is supported by further work it will add significantly to the known extent of the Beltian rocks.

OREGON

Mount Jefferson primitive area studied

Mapping in the Mount Jefferson primtive area in the Cascade Range of Oregon by G. W. Walker and R. C. Greene (r0325) indicates that the area is part of an elongate north-trending volcanic plateau that is surmounted by several major volcanoes which are presently dormant and possibly extinct. Walker and Greene have recognized an older series of flows, breccias, and sedimentary rocks, and a younger series of flows and pyroclastic deposits. The older series is correlative with volcanic rocks of the western Cascade Range, and the younger series, which ranges in composition from dacite to basalt, belongs to the volcanic rocks of the High Cascade Range. (See also "Mineral Resources" under "Investigations of Natural Resources.")

Filled submarine lava tubes in Eocene basalt

P. D. Snavely, Jr., (r0029) has found filled submarine lava tubes within the uppermost part of the Siletz River Volcanic Series of Eocene age. The tubes, 100 to 200 feet wide and 50 to 100 feet high, are lens shaped in cross section and are enclosed by pillow basalts which apparently insulated the lava in the tubes from sea water during cooling. The basalt filling has well-developed columnar joints that converge towards the centers of the tubes. One small, filled tube consists of fine-grained alkalic basalt at the base and grades upwards into porphyritic augite basalt. This relationship between alkalic basalt and augite-rich basalt within a single cooling unit suggests that these two basalts were pumped out of a shallow magma reservoir in which crystal fractionation had taken place.

CALIFORNIA

Electron-microscope examination of Franciscan limestone

R. E. Garrison, of the University of California at Santa Barbara, working with E. H. Bailey, of the U.S. Geological Survey, has discovered by electron-microscope examination of the red Laytonville type of limestone from the Franciscan Formation that much of the micrite (ultra-fine-grained part) of the rock consists of coccoliths. Because of their ubiquitous areal association with mafic volcanic rocks, these limestones were heretofore regarded as largely of inorganic origin.

A two-amphibole glaucophane schist from Franciscan Formation

D. E. Lee, R. G. Coleman, Harry Bastron, and V. C. Smith have studied in detail (p. C148–C157) a tectonic block of glaucophane schist of the Franciscan Formation in Sonoma County in which the primary assemblage actinolite-glaucophane-garnet-epidote has been partly replaced by retrograde chlorite and pumpellyite. Their results are consistent with the hypothesis that the primary mineral assemblage is that of a high-grade schist formed at depth and emplaced in its present environment by upward tectonic movement.

Lawsonite-glaucophane schist near Yreka

P. E. Hotz has found lawsonite-glaucophane schist within a belt of highly deformed schists, siliceous phyllites, and greenstones in northern Siskiyou County, Calif. This schist, indicative of metamorphism under conditions of high temperature and low pressure, occurs in metamorphic terrane whose rocks were previously referred to the pre-Silurian(?), but now are believed to be metamorphosed cherts and metavolcanic rocks tentatively correlated with the Triassic Applegate Group of southern Oregon. A highly sheared body of serpentinite parallels the deformed rocks and separates them from structurally overlying Silurian and possibly Ordovician sedimentary rocks on the southeast.

Oxide ratios of Mesozoic graywackes

Chemical analyses of 12 graywacke samples, collected along the northwest margin of the Sacramento Valley by R. D. Brown, Jr., and E. I. Rich from a Late Jurassic to Late Cretaceous section more than 40,000 feet thick, show distinctive trends in oxide ratios. These trends agree closely with those previously established for eugeosynclinal sandstone.[37] The analytical data for the northern California rocks are more uniform, however, and the change in oxide ratios from one part of the section to another is more nearly linear than that from studies of the chemical composition of sandstones. Comparisons of FeO, Fe_2O_3, and MgO content suggest higher concentrations of mafic volcanic rock debris in stratigraphically lower samples, a relationship corroborated by petrography and fieldwork.

[37] G. V. Middleton, 1960, Chemical composition of sandstones: Geol. Soc. America Bull., v. 71, p. 1011–1026.

Distribution of fossils suggests large displacement along San Andreas fault

Newly discovered marine mollusks, reported by W. O. Addicott from the Tertiary Skooner Gulch Formation of Weaver near Point Arena, in northwestern California, mark the northernmost occurrence of *Turritella inezana*, a warm-water faunal element characteristic of the Vaqueros Stage of the Pacific Coast megafaunal chronology. Southward, comparable sublittoral assemblages containing this warm-water gastropod and associated Vaqueros mollusks have been previously reported from the Santa Cruz Mountains of coastal California, but do not occur north of the San Benito area of the interior part of the California Coast Ranges. This distribution suggests that there may have been post-early Miocene lateral movement on the San Andreas fault as great as 120 miles.

Data on late Tertiary volcanism in Sierra Nevada

Mapping of the volcanic rocks in the Devil's Postpile quadrangle of the Sierra Nevada by N. K. Huber and C. D. Rinehart[38] (Huber and Rinehart, r1697) resulted in the delineation of 11 map units ranging in composition from basalt to rhyolite. The upper Pliocene to Recent volcanic suite is alkalic-calcic and includes one rhyolitic welded ash-flow tuff. Although geographically isolated by the Sierra Nevada drainage divide, the welded ash-flow tuff is probably correlative with the Bishop Tuff. Recently obtained radiocarbon dates from this general region indicate that phreatic gas explosions occurred between 500 and 850 years ago and formed craters more than 600 feet in diameter (Rinehart and Huber, r1593).

Geology of San Rafael primitive area

The San Rafael primitive area in the San Rafael and Sierra Madre Mountains, at the southern end of the Coast Ranges, has been mapped by H. D. Gower and others (r2016) who have found that the region is underlain by more than 22,000 feet of moderately to intensely deformed sedimentary rocks of Late Cretaceous to middle Miocene age.

[38] N. K. Huber and C. D. Rinehart, 1965, The Devils Postpile National Monument: California Div. Mines and Geology, Mineral Inf. Service, v. 18, no. 6, p. 109–118.

Deformation occurred after each episode of sedimentation recorded by the Cretaceous, Eocene, and Miocene rocks, so that Cretaceous strata generally dip more steeply than Eocene, and Eocene more steeply than Miocene, and unconformities separate the main sedimentary sequences. (See also "Mineral Resources" under "Investigations of Natural Resources").

Ages of Pacific coast marine terraces

A previously unrecognized marine terrace platform occurring at a level intermediate to the "Dume" and "Malibu" platforms described by W. M. Davis [39] has been mapped by R. F. Yerkes and C. M. Wentworth during the course of geologic studies in the Santa Monica Mountains north of Los Angeles. This terrace and the two named by Davis have been mapped along the Malibu coast between Point Dume and Malibu Canyon. The elevations of the landward margins of the bedrock platforms at their intersection with the old sea cliffs in this area are about 110 feet ("Dume"), 176 feet (intermediate), and 250 feet ("Malibu"). Marine deposits occur on the two lower terraces and have been dated provisionally by the uranium-series disequilibrium method by J. N. Rosholt, Jr., (open-system model) at about 125,000 years ("Dume") and 180,000 years (intermediate), thus establishing the relative ages of the two terraces.

Tectonic uplift of south end of San Joaquin Valley

A recent report by B. E. Lofgren (p. B6–B11) deals with continuing tectonic movements in the Grapevine area at the southern end of the San Joaquin Valley. Tectonic movements during the destructive Arvin-Tehachapi earthquake of 1952 caused a differential uplift of as much as 2 feet in the Tehachapi Mountains south of Wheeler Ridge. Periodic releveling since 1952 indicates an axis of continuing flexure 2 miles south of Grapevine. It is not known, however, whether the axis area is rising or the areas north and south of the axis are subsiding. In either case, tectonic movement in the mountains evidently is continuing.

Andesitic volcanism in south-central Mojave Desert

Geologic mapping by T. W. Dibblee, Jr., near Ludlow, in the south-central Mojave Desert, Calif., has delineated a thick sequence of Tertiary volcanic rocks that were extruded onto a surface of uneven relief. The basement upon which the flows were extruded consists of Mesozoic granitic rocks. The central portion of the volcanic eruption is composed of andesite or dacite porphyry. Extending for tens of miles in all directions from this core of porphyry are flows, flow breccias, and tuff breccias which aggregate more than 15,000 feet in thickness in places. Extreme thickening and thinning of the section appear to occur in very short distances. Hydrothermal leaching has affected much of the porphyry of the central core. The numerous old gold mines and prospects of the Stedman mining district are found along or near the contact of the leached and the unaltered porphyry. The mineralized rock contains gold and silver along with oxides of iron, manganese, and copper.

Stratiform thrust sheets in central Santa Monica Mountains, Calif.

R. H. Campbell, R. F. Yerkes, and C. M. Wentworth have found that the central Santa Monica Mountains consist of an autochthon and three detachment thrust sheets containing rocks of Late Cretaceous to middle Miocene age (p. C1–C11). The thrust sheets, which are superposed on each other in a stratiform manner, are folded, faulted, and dilated by igneous intrusion.

ALASKA

Figure 4 is an index map showing the boundaries of the regions referred to in the following summary of scientific and economic findings of recent geologic and geophysical studies in Alaska.

NORTHERN ALASKA

Gravity low over Colville geosyncline

D. F. Barnes reports that progress on the preparation of the Alaska gravity map included completion of more than a thousand reconnaissance measurements north of the Noatak and Kobuk Rivers. The newly completed map shows that the Colville geosyncline is characterized by a broad gravity low that is present along the entire north flank of the Brooks Range and that extends onto the continental shelf west of Point Lay. This gravity low deepens toward the center of the range, where the only belt of large positive anomalies was found on the south flank. The general form of the Brooks Range gravity anomaly is typical of other overthrust mountain ranges and suggests that the root of the thrusts may be associated with this belt of positive anomalies which extends through Bettles and the forks of the Chandalar Rivers.

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[39] W. M. Davis, 1933, Glacial epochs of the Santa Monica Mountains, California: Geol. Soc. America Bull., v. 44, no. 10, p. 1041–1133.

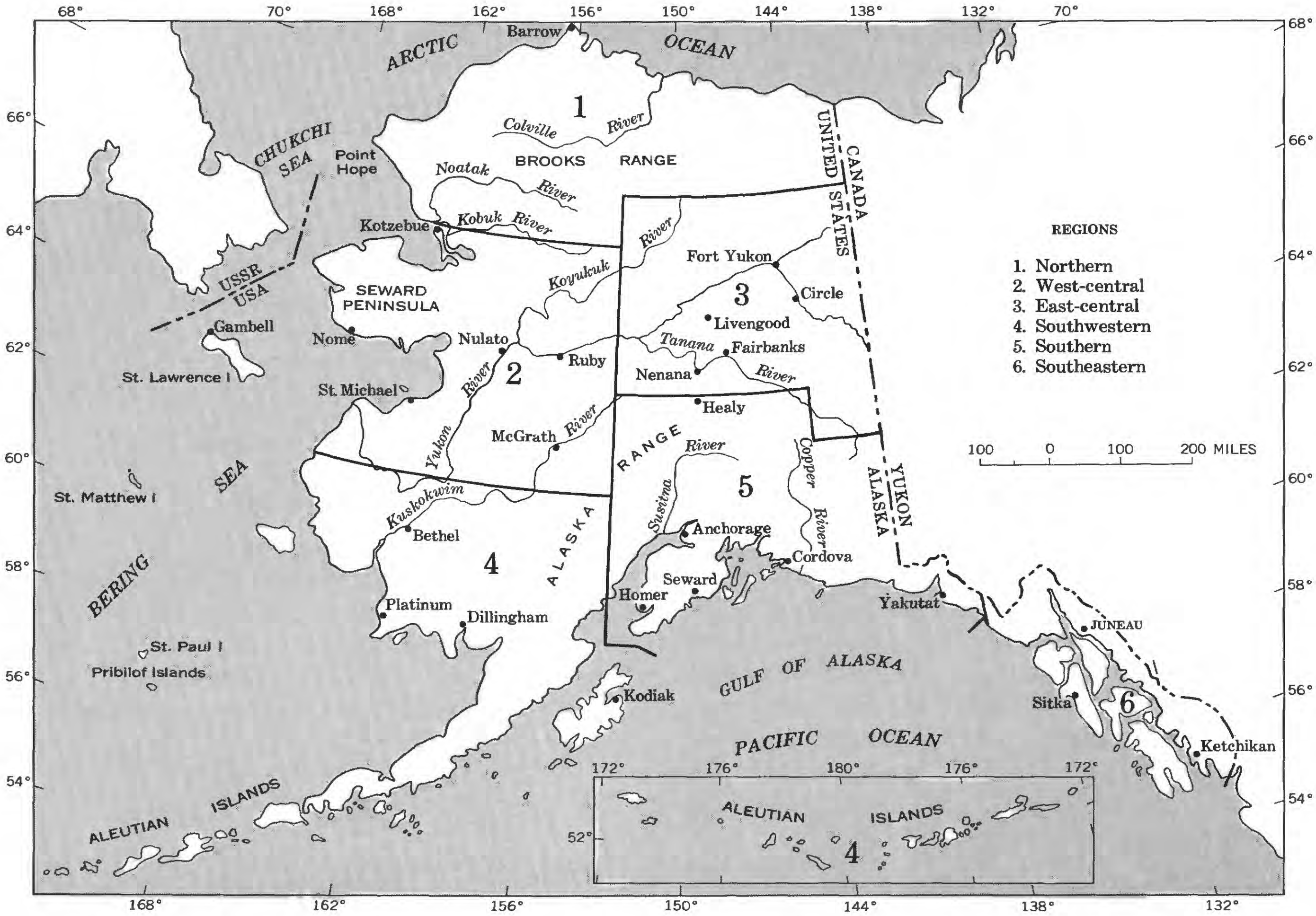

FIGURE 4.—Index map of Alaska, showing boundaries of regions referred to in discussion of Alaska geology.

Occurrence of pyrophyllite in Kekiktuk Conglomerate

B. L. Reed and J. J. Hemley (p. C162–C166) have found that pyrophyllite occurs in the matrix of quartzite and conglomerate of the Upper(?) Devonian or Mississippian Kekiktuk Conglomerate in the northeastern Brooks Range. Pyrophyllite replaces quartz and probably formed by reaction between kaolinite and quartz under conditions of low-grade metamorphism.

Clay-shale unit traced over extensive area

A clay shale has been traced by I. L. Tailleur for 380 miles eastward from the Ipewik River, where it lies beneath Lower Cretaceous strata, and from the DeLong Mountains, where it overlies Triassic strata. Paleontological studies by D. L. Jones and R. W. Imlay show that this unit contains rocks of both Jurassic and Cretaceous age. In the southwest, the clay shale is Late Jurassic in age; in the northwest, Early Jurassic and Early Cretaceous (Valanginian); in the east, Early Cretaceous.

Multiple overthrusting in Nuka-Etivluk Rivers region

In the Nuka-Etivluk Rivers region, investigation of oil-shale occurrences reported by I. L. Tailleur confirmed that bituminous rock is present in three different stratigraphic sequences juxtaposed by faulting. Field checking of contrasts within these and other units has strengthened the hypothesis of multiple gross overthrusting to explain the chaotic distribution of rocks in the region.

Thrust sheets recognized in DeLong Mountains

I. L. Tailleur reports that fieldwork in the western DeLong Mountains reveals at least 3 different stratigraphic sequences as well as 1, possibly 2, broadly folded overthrust sheets. One thrust sheet, which extends discontinuously to the west coast, is composed of mafic rocks and Paleozoic limestone, and may be coextensive with the largest thrust in the Nuka-Etivluk region, 100 miles to the east.

WEST-CENTRAL ALASKA

Wisconsin-age glaciation of western Seward Peninsula

Studies by C. L. Sainsbury have shown that a Wisconsin-age ice sheet advanced northward from the York Mountains, at least as far as the present shoreline of Lopp Lagoon on the Chukchi Sea. Ice overrode hills 1,400 feet high along the north front of the mountains and at many places in the westernmost Seward Peninsula and adjoining Bering Strait. Destruction of the marine Lost River terrace of Sangamon age correlates with the glacial advance. Redistribution of sediment by the piedmont ice sheet accounts for some anomalous locations of traces of tin in streams of the western Seward Peninsula.

Pleistocene history of Alaskan coast of the Chukchi Sea

Studies by D. S. McCulloch in the unconsolidated sediments of the Alaskan coast of the Chukchi Sea record evidence for 2 major glacial advances and 4 marine transgressions ranging in age from late Pliocene(?) or early Pleistocene(?) to Sangamon. An early Recent warm period that began about 10,000 years ago and lasted until at least 8,300 years ago is also documented. The south-central portion of the coastal plain has been differentially upwarped since the time of the next to oldest transgression.

Plutonic belt in west-central Alaska

T. P. Miller, W. W. Patton, Jr., and M. A. Lanphere have found that a belt of plutons in west-central Alaska is divisible into an older, 100-million-year old suite of monzonite and syenite and a younger, 81-m.y.-old suite of granodiorite and quartz monzonite (p. D158–D162). The western part of the belt contains the older plutons.

EAST-CENTRAL ALASKA

Devonian age of part of Tolovana Limestone

The Tolovana Limestone, long mapped as Silurian, is now known to include fossils of Middle to early Late Devonian age. Collections by F. R. Weber from a locality on the Elliott Highway at mile 39 near Globe Creek were grouped with earlier collections from the Livengood quadrangle and studied by W. A. Oliver, Jr. A Devonian age was assigned on the basis of a coral, *Dendrostella rhenana* (Frech) and a stromatoporoid, *Amphipora* sp.

Inclusions in alkali-olivine basalt, Yukon-Tanana Upland

Lava of Prindle Volcano contains inclusions of peridotite and hypersthene granulite, inclusions that tend to be mutually exclusive in similar volcanoes. Granulite-facies rocks are not known in the Yukon-Tanana Upland. Therefore, it seems likely, according to H. L. Foster, R. B. Forbes, and D. M. Ragan (p. B115–B119), that the granulite inclusions came from the deep crust.

Eastward continuation of thrust plate in Wiseman quadrangle

Geologic mapping by W. P. Brosgé and H. N. Reiser has disclosed that a synclinal thrust plate, originally recognized west of the John River, also extends east of the river for a distance of 12 miles. Middle and Upper Devonian clastic and carbonate rocks of the thrust plate overlie a normal Middle(?) and Upper Devonian sequence of Skajit Limestone and Hunt Fork Shale. In the lower part of the thrust plate, Middle Devonian calcareous clastic rocks contain clasts of volcanic rock. Higher in the plate, an Upper(?) Devonian unit of thinly interbedded black siltstone and limestone appears to correlate lithologically with rocks at Bornite in the Cosmos Hills, 150 miles to the southwest.

SOUTHWESTERN ALASKA

Aleutian Trench sediments

The predominant constituents of sediment in the Aleutian Trench are found to be quartz, muscovite, and chlorite. G. W. Moore believes that these minerals were derived from the low-grade metamorphic terrane of south-central Alaska rather than from volcanic rocks of the nearby Aleutian Islands. These components of the Aleutian Trench sediment were probably deposited by turbidity currents that traveled along the trench axis for distances of hundreds of kilometers.

Illinoian-age glaciation in Pribilof Islands

On St. George Island in the Pribilof Islands Group, evidence of former glaciation was confirmed by investigations of D. M. Hopkins and Thorleifur Einarsson. During Illinoian time St. George Island supported several small cirque glaciers and a single ice cap having an area of about 12 square kilometers. The island was not glaciated during Wisconsin time although some cirques and ice-eroded features were sharpened by nivation beneath persistent snowbanks. Their studies (Hopkins and Einarsson, r0591) reveal a snowline altitude at 150 meters during Illinoian time and one higher than 200 m during the later cold cycle when glaciers were lacking. Other islands of the Pribilof Group lack evidence of former glaciation.

Cretaceous stratigraphy of Kamishak Hills, Alaska Peninsula

Studies in the Kamishak Hills by D. L. Jones and R. L. Detterman (p. D53–D58) show that Cretaceous rocks rest conformably on Upper Jurassic strata and are divisible into two formations. The lowermost formation, of Early Cretaceous age, is unnamed and has two members. The lower member consists of 200 feet or more of gray shaly siltstone that includes numerous 1-foot-thick beds of *Inoceramus*-prism calcarenite. It is of late Hauterivian to early Barremian age, based on the presence of *Inoceramus ovatoides*, and is equivalent to the Herendeen Limestone of the Port Moller area. The upper member consists of 200–300 feet of rusty brownish-gray siltstone that contains belemnites and the ammonite *Acrioceras* cf. *A. starrkingi* Anderson of Barremian age. This is the first known occurrence of strata of these ages on the Alaska Peninsula.

The uppermost Cretaceous formation, the Kaguyak Formation, overlies the Lower Cretaceous beds with slight angular unconformity and on the basis of the ammonites it contains it is Maestrichtian (latest Cretaceous) in age.

SOUTHERN ALASKA

Early Tertiary age of Orca Group in Prince William Sound

George Plafker and F. S. MacNeil report (p. B62–B68) that the Orca Group is lower Tertiary, most probably Eocene, and not Mesozoic, as previously supposed. Stratigraphic reconnaissance and review of available paleontologic evidence suggest that the Orca Group and coeval rocks elsewhere along the Gulf of Alaska were part of a Tertiary basin that extended from the Katalla district on the east through Prince William Sound to the southeast coast of Kodiak Island. It is postulated that a period of major orogeny culminated in late Eocene or early Oligocene time and caused complex folding and faulting of the basin; accompanying granitic intrusion mav have been the origin of widespread copper, gold, and antimony mineralization in the Prince William Sound region.

Age of intrusive rocks in Prince William Sound region

M. A. Lanphere and Arthur Grantz report K/Ar ages ranging from 34 to 42 million years from samples of granitic rocks from the Prince William Sound region. Those plutons appear to lie along a northeasterly extension of a belt of granitic plutons that runs through Kodiak Island and the Shumagin Islands. Plutons in the Kodiak-Shumagin region, however, yield ages ranging from 57 to 60 m.y., indicating emplacement in the early Tertiary.

Four plutons in the Prince William Sound region that have been investigated by M. A. Lanphere have biotite and hornblende whose K/Ar ages range from 34.4 to 36.6 m.y. and the mean age of which is 35.8 m.y. These data more closely define the time of intrusion of these 4 plutons as early in the Oligocene.

Gravity anomalies in southern Alaska earthquake belt

Gravity surveys which formed part of the Alaska earthquake investigations of both the U.S. Geological Survey and the U.S. Coast and Geodetic Survey have delineated several large anomalies in the southern Alaska earthquake belt. Two of the most prominent anomalies, according to D. F. Barnes and J. E. Case, are belts of gravity highs that are subparallel to the Aleutian-Alaska Range volcanic arc for several hundreds of miles. One of these anomaly belts follows the igneous rocks of the Seldovia geanticline from southwestern Kodiak Island to the southeast corner of the Copper River Basin and includes anomalies as high as +67 milligals on Ushagat Island at the entrance to Cook Inlet. The second belt follows the south edge of the Chugach Mountains and extends from the continental margin at the southernmost corner of Kodiak Island to the junction of the Copper and Tasnuna Rivers east of Valdez. The anomaly is best developed over outcrops of igneous rocks on Knight Island in Prince William Sound, where calculations suggest that it could be caused by a 40,000-foot-thick prism of these rocks.

Upper Mesozoic stratigraphy in southwestern Wrangell Mountains

Investigations by Arthur Grantz, D. L. Jones and M. A. Lanphere provide new information on the stratigraphy, age, and timing of geologic events in the upper Mesozoic rocks of the southwestern Wrangell Mountains (p. C39–C47). These studies document 3 episodes of deep erosion and subsequent transgression as well as 3 episodes of plutonism within the Matanuska geosyncline during the interval Middle Jurassic to Late Cretaceous.

Copper deposits related to Tertiary intrusives

E. M. MacKevett, Jr., suggests that the copper deposits of the Kennecott district in the southern Wrangell Mountains are associated with Tertiary intrusive rocks. Plutonic rocks near the copper deposits represent shallow phases of extensive Tertiary volcanism and include granodiorite and fine-grained felsic varieties that formed later than the granodiorite; both types locally have deformed their wallrocks. Some dikes cut the felsic plutons and also cut a few of the ore bodies. Current knowledge of the geology near the Kennecott deposits is compatible with the speculation that the deposits are genetically related to a concealed, probably granodioritic pluton. MacKevett and A. S. Radtke (p. B165-B168) also have recognized hydrothermal alteration near the Kennecott copper deposits that consists of an early dolomitic phase and a later jarosite-illite-potassium feldspar phase. Recognition of this hydrothermal alteration may be useful as a guide to prospecting for additional deposits.

SOUTHEASTERN ALASKA

Contrasting structural habit of plutons in Coast Range batholith

Investigations by D. A. Brew and A. B. Ford in the Juneau Icefield part of the Coast Range batholithic complex have revealed strong contrasts in structural habit between the two largest intrusive masses. The westernmost pluton is a late-kinematic, generally concordant foliated and lineated hornblende tonalite that was involved in the youngest deformations which affected the surrounding schists and gneisses. The easternmost intrusion is a somewhat discordant body of biotite-hornblende granodiorite with weak flowage foliation; it lacks signs of deformation and is probably postkinematic.

Age of some ultramafic intrusions in southeastern Alaska

According to M. A. Lanphere and G. D. Eberlein, potassium-argon ages of biotite and hornblende from eight ultramafic complexes in southeastern Alaska indicate emplacement during the same igneous event in the middle part of the Cretaceous, probably during the interval 100–110 million years. These studies, however, do not suggest contemporaneity of all ultramafic bodies in southeastern Alaska because similar ultramafic rocks were emplaced in at least three localities during the early Paleozoic.

PUERTO RICO

Volcanic rocks of central Puerto Rico

P. H. Mattson and A. E. Nelson (r2057) have found systematic variations and differences within the Cretaceous volcanic sequence of central Puerto Rico. Nelson has shown that there is a continuous chemical variation from the older basalt lavas flows to the younger rhyolitic tuffs (p. D172–D177). Rocks of the Rio Orocovis Group [40] and correlated units have alkaline affinities, whereas older and younger volcanic rocks are calc-alkaline.

Volcanic rocks of the dacite-rich Jacaguas Group of Pessagno, of latest Cretaceous(?) to middle Eocene age are similar in composition to plutonic rocks of the penecontemporaneous Utuado batholith, according to Lynn Glover 3d. Facies relations indicate that volcanic vents in the vicinity of the batholith were sources of pyroclastic materials in the Jacaguas Group. The volcanic and plutonic phenomena here were therefore transitional.

Metamorphism in central Puerto Rico

Low-grade metamorphic facies in central Puerto Rico range in grade from zeolite to greenschist, and recent studies by Lynn Glover 3d have shown that the isograds cut abruptly across stratigraphic boundaries. Thus, the metamorphism is not related simply to depth of burial, as had been suggested.

Stratigraphic correlations between central and northeast Puerto Rico

V. M. Seiders, of the U.S. Geological Survey, and Dr. E. A. Pessagno, Jr., of the University of California at Davis, have correlated rocks of northeastern Puerto Rico with the relatively well known sequence of the central part of the island. This was done by dating the planktonic Foraminifera that occur in a few, rare beds in a thick sequence of clastic volcanic rocks in the northeast part of the island. The data also indicate that here (1) Cenomanian strata are more than 2,000 meters thick; (2) Turonian, Coniacian, and Santonian strata comprise only about 200 m; and (3) Campanian rocks are about 1,000 m thick, whereas the Maestrichtian appears to be thin or absent. Probable lower Paleocene to lower Eocene strata also are recognized.

Faults in south-central and central Puerto Rico

Lynn Glover 3d has found evidence in south-central Puerto Rico for fault-line scarps trending parallel to the main west-northwest-trending fracture system of the island. These old faults suggest that the main system, which is chiefly characterized by sinistral wrench faulting and high-angle reverse faulting, has been active since well back in Cretaceous time. Glover also concludes that a conspicuous set of north- and northwest-trending faults in central Puerto Rico consists of perianticlinal and normal cross faults related to the Late Cretaceous folding on the crestal anticline of the Barranquitas anticlinorium. They thus

[40] H. L. Berryhill, Jr., 1965, Geology of the Ciales quadrangle, Puerto Rico: U.S. Geol. Survey Bull. 1184, 116 p.

may record a separate episode of faulting apart from the main fracture system.

Copper anomaly found in central Puerto Rico

Anomalously high (100–600 parts per million) concentrations of copper have been found in unaltered clastic volcanic rocks and lavas of the Cretaceous Robles-Río Orocovis sequence in central Puerto Rico; most plutonic rocks and most other volcanic rocks in Puerto Rico have a low copper content (10–100 ppm). Recently discovered large, low-grade copper deposits in central Puerto Rico occur in and adjacent to latest Cretaceous to Eocene plutons emplaced in the Robles–Río Orocovis sequence. R. P. Briggs (r1485), P. H. Mattson, and Lynn Glover 3d suggest that the copper ore may have originated through hydrothermal concentration of copper contained the Robles-Río Orocovis rocks.

ANTARCTICA

The U.S. Geological Survey, during the 1965–66 austral season in the Antarctic, successfully accomplished a multidiscipline program of earth-science study in the remote Pensacola Mountains (fig. 5). This was the first such combined investigation to make cooperative use of high-performance turbine helicopters in Antarctica. Fieldwork was conducted by 16 scientists and engineers of the U.S. Geological Survey on 7 projects that included geologic mapping, geophysics, geodetic control and support, paleobotany, and glaciology. This program is part of the U.S. Antarctic Research Program supported and coordinated by the U.S. National Science Foundation and logistically sustained by the U.S. Navy Operation Deep Freeze; three helicopters were provided and flown by the U.S. Army. Geologic topical studies of other parts of West Antarctica were continued in laboratories and offices of the Geological Survey. Topographic and planimetric maps are compiled by the Topographic Division of the Geological Survey (see section "Topographic Surveys and Mapping, Mapping in Antarctica").

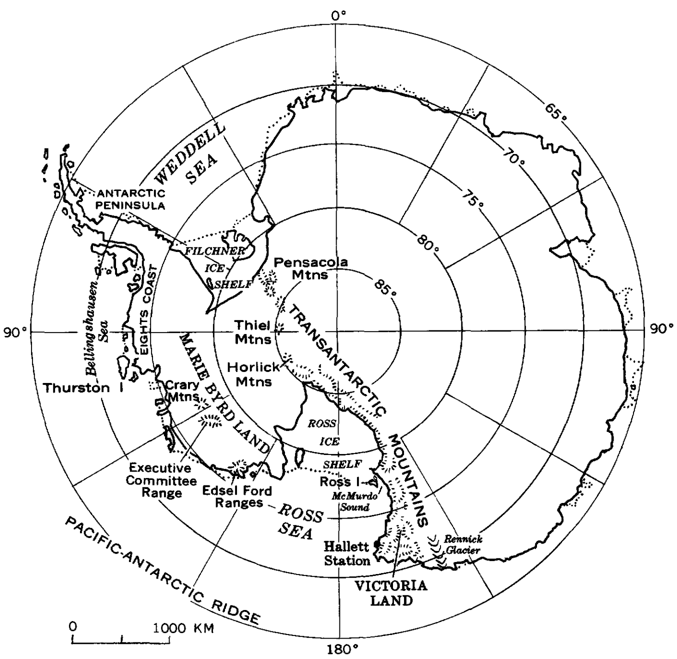

FIGURE 5.—Index map of Antarctica.

Reconnaissance of northern Pensacola Mountains and adjacent areas

The northern Pensacola Mountains are composed of folded sedimentary rocks and a stratiform body of gabbro. Mapping by D. L. Schmidt and W. H. Nelson of about half of the northern Pensacola Mountains indicates that they consist of folded, interbedded graywacke and slate (Patuxent Formation) of Precambrian age unconformably overlain by Nelson Limestone, volcanic rocks, and shale of Cambrian age, which, in turn, are unconformably overlain by sandstone of middle Paleozoic age (D. L. Schmidt and others, r0388). The middle Paleozoic and older rocks are overlain by the Gale Mudstone of Permian(?) age and overlying coal- and glossopterid-bearing siltstone and shale of Permian age. The Gale Mudstone is a diamictite containing clasts of all the older sedimentary and igneous rocks of the area, and is believed to be a tillite. The Permian rocks in the northern Pensacolas were broadly folded at the same time that the middle Paleozoic rocks were folded but before the intrusion of the stratiform gabbroic rock.

Three areas outside the Pensacola Mountains were mapped for the first time by Schmidt and Nelson. A group of nunataks, 120 kilometers southwest of the Neptune Range, consist of intensely folded, rhythmically interbedded graywacke and slate (Patuxent Formation) of Precambrian age and folded quartz sandstone that unconformably overlies graywacke. The Mount Ferrara area, 95 km east of the Forrestal Range, consists of isoclinally folded Cambrian Nelson Limestone containing abundant archaeocyathids. The Mount Spann area, 120 km northeast of the Forrestal Range, consists of interbedded quartzite and siltstone that probably underlies the Nelson Limestone and is probably much thicker than 1,000 meters. This unit is not exposed in the Pensacola Mountains, and its relation to the Patuxent Formation is not known.

Dufek stratiform gabbro

Stratiform gabbroic rock in the Dufek Massif and Forrestal Range of the northernmost Pensacola Mountains has been mapped and sampled by A. B. Ford and W. W. Boyd, Jr. If the mafic rock of these two ranges is part of a single intrusion, as seems likely, it is one of the largest stratiform bodies of the world; it is exposed over an area of at least 8,000 square kilometers and has a minimum thickness of 2,000 m. Widespread feldspathic pyroxenite, in layers 1 to 3 m thick, and less widespread magnetite layers and lenses lie with sharp contact on thick layers of anorthosite or leucogabbro and grade upward into thick layers of gray gabbro. Centimeter-scale rhythmic layering is characteristic. Numerous channel-like structures, tens of meters wide, are filled with layered pyroxenites, iron oxides, anorthosite, and leucogabbro with sharp basal contacts. The rock filling the channels grades across an upper contact into normally interlayered gabbroic rock. These channels may have been formed by convection currents. Neither the base nor top of the stratiform pile is exposed, but fine-grained chilled phases locally border contact-metamorphosed Paleozoic quartz sandstone. The layers dip about 10° SE. The gabbro has been uplifted along high-angle faults bordering the southeastern margin of the Filchner Ice Shelf. Its age is uncertain, but a post-Permian age is indicated by the metamorphic effects on nearby carbonaceous, glossopterid-bearing sedimentary rocks.

Geophysics of Pensacola Mountains

Geophysical investigations carried out over an area of 120,000 square kilometers in and adjacent to the Pensacola Mountains (J. C. Behrendt and others, r0944) consisted of a seismic-reflection and gravity survey by J. C. Behrendt, L. J. Meister, and W. L. Rambo and an aeromagnetic reconnaissance by J. R. Henderson. Seismic reflections indicate that the Filchner Ice Shelf is 1,250 meters thick near its southern margin west of the Dufek Massif. A major ice stream, about 3,000 m thick and overlying a channel 2,000 m below sea level, enters the Ice Shelf from between the Forrestal Range and Mounts Spann and Ferrara. A second major ice stream, about 2,500 m thick and overlying a channel as deep as 2,000 m below sea level, enters the Ice Shelf from between the Neptune and Patuxent Ranges. A much wider ice stream, more than 2,000 m thick, lies between the Patuxent Range and the Thiel Mountains. Within and to the northwest of the Pensacola Mountains, Bouguer anomalies decrease abruptly from +70 to −80 milligals across the boundary from West to East Antarctica. This strong gravity gradient of 2 mgal/km is probably associated with crustal thinning. The aeromagnetic data from 6,000 km of traverse delineate anomalies up to 1,800 gammas associated with the stratiform gabbroic body of the Dufek Massif and Forrestal Range and suggest a minimum areal size of 9,500 sq km.

Antarctic paleobotany

Devonian and Permian fossil plants and coal in Victoria Land, in the Ohio Range of the Horlick Mountains, and in the Pensacola Mountains were collected and studied by J. M. Schopf and J. F. Rigby during the 1965–66 field season. Fossil plants provide the best data at present for solving geologic facies and correlation problems in the upper Paleozoic and Mesozoic rocks of the Transantarctic Mountains. Schopf also collected a new and unique assemblage of archaeocyathids and trilobites at Mount Spann, 120 km northeast of the Pensacola Mountains.

New Cambrian fossils from Antarctica

A. R. Palmer has identified a new assemblage of Cambrian trilobites from Antarctica in collections made by V. H. Minishew, of Ohio State University. The fossils share a general Asiatic aspect with other Cambrian assemblages that have come from Antarctica. This represents the third geographic area in the south polar regions at which a distinct trilobite fauna has been collected.

Age and correlation of rocks in Marie Byrd Land

The K-Ar age of biotite from alkaline granite of the Clark Mountains, in the Edsel Ford Range of Marie Byrd Land, determined by R. F. Marvin, H. H. Mehnert, and Wayne Mountjoy, is 143±4 million years, which corroborates the tentative Late Jurassic to Early Cretaceous age reported on the basis of Sr-Rb studies on K-feldspar (139±9 m.y.) and whole rock (116±10 m.y.) by F. G. Walthall and C. E. Hedge. According to E. L. Boudette and others (p. D190–D194), a minimum age is thus established for metamorphosed graywacke intruded by a granite in the Clark Mountains; the graywacke is possibly much younger than its postulated Ordovician age. A K-Ar biotite age of 109±3 m.y. for quartz gabbro from Mount Aldaz, in the Executive Committee Range of Marie Byrd Land, was determined by Marvin, Mehnert, and Mountjoy. Boudette and others (p. D190–D194) believe that this age is not in harmony with the regional stratigraphic relations that indicate that the gabbro is much older than the granite of the Clark Mountains. It is likely that the biotite was recrystallized during the metamorphism and metasomatism of the parent rock. Boudette and A. A. Drake, Jr., continue to tentatively correlate the Mount Aldaz gabbroic rock with the oldest known gabbro (pre-early Mesozoic) on the Eights Coast which is texturally and petrochemically similar.

K-Ar ages of 150±4 m.y. for biotite and 135±14 m.y. for hornblende, determined by R. F. Marvin from granodiorite collected at Landfall Peak, Thurston Island, reinforce the previous interpretation that the Eights Coast–Thurston Island composite batholith is approximately 150 m.y. old according to A. A. Drake, Jr. The rocks at this locality differ from those along the Eights Coast in that they have not been affected by a subsequent thermal event. Andean plutonism therefore was not active in this area.

The anorthoclase trachyte facies of the Quaternary alkaline basalt-trachyte province in West Antarctica is comparable to a similar facies on the East Pacific Rise. E. L. Boudette suggests that the two provinces may be connected through the Pacific-Antarctic submarine ridge.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

During fiscal year 1966, the U.S. Geological Survey continued its program of assistance to developing nations, which began more than a quarter of a century ago, and increased its international scientific and technical cooperation through participation in the work of the U.S. Department of State, the United Nations, and other organizations. The Survey's intensified international activities were in keeping with the objectives of the International Cooperation Year, designated for 1965 by the United Nations to explore ways of increasing the flow and effectiveness of international cooperation. In the United States, national deliberations to review past accomplishments and new approaches to cooperation led to the White House Conference on International Cooperation, November 28–December 1, 1965; the deliberations of the National Citizen's Commission, to which the Survey contributed during the conference, are summarized in the Report of the Committee on Natural Resources, Conservation and Development. During 1966, the Geological Survey participated in scientific and technical programs of the International Union of Geological Sciences, the Commission for the International Hydrological Decade, the Commission for the Geological Map of the World, the CENTO Working Party on Mineral Development, the United Nations Economic Commission for Asia and the Far East, and other commissions dealing with geologic, hydrologic, and topographic surveys. Ninety-seven Survey specialists represented the United States at 59 meetings of such international commissions during the year. In addition, Survey personnel continued participation in the scientific-interchange program in volcanology, under the cooperative agreement between Japan and the United States through the National Academy of Sciences, and participated in a National Academy of Sciences workshop in Peru.

Under the Geological Survey's technical-assistance program, 135 specialists were assigned during 1966 to 28 countries at the request of other governments, and academic or practical study was conducted or arranged in the United States for 109 geologists and engineers from abroad. Table 1 summarizes the type of assistance given to each country during the year. In more than 25 years of technical assistance, the Geological Survey has sent 648 members of its staff on investigations and training assignments to 70 countries, and has provided training in the United States for 851 scientists from 71 countries.

The U.S. Geological Survey technical-assistance projects are operated under government-to-government agreements through the U.S. Department of State. Most of these projects involve assistance in strengthening earth-science institutions or cadres of scientists, together with geologic mapping and appraisal of host-country resources or investigations of geologic phenomena that affect social and economic development. During fiscal year 1966 the Survey, in cooperation with counterpart agencies, conducted joint broad-scale projects involving institution-building and geologic or hydrologic surveys in 13 countries: Bolivia, Brazil, British Guiana, Colombia, Egypt, Liberia, Nigeria, Afghanistan, Kuwait, Nepal, Pakistan, Saudi Arabia, and Korea. Special studies of geologic or hydrologic phenomena, or short-range advisory assistance projects on geologic and hydrologic problems, were undertaken jointly with counterparts in 19 countries: Argentina, Brazil, Chile, Costa Rica, Jamaica, Peru, Venezuela, Dahomey, Ethiopia, Nigeria, Greece, India, Iran, Jordan, Pakistan, Saudi Arabia, Philippines, Thailand, and Viet Nam.

More than 800 technical and administrative documents involving Survey authors have been issued as a result of the Geological Survey's technical-assistance program. A recent bibliography by J. A. Heath[41] lists 685 of these documents which were published as of the end of 1964; the bibliography does not include a large number of reports published by counterpart agencies but not involving Survey authors. Ninety-five technical and administrative documents were issued during fiscal year 1966 (table 2).

Some of the more significant results of Geological Survey investigations abroad are summarized in the following paragraphs.

[41] J. A. Heath, 1965, Bibliography for reports resulting from U.S. Geological Survey participation in the United States technical assistance program, 1940–65: U.S. Geol. Survey Bull. 1193, 51 p.

TABLE 1.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1966*

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity[1]	Number	Field of training
Latin America					
Argentina	1	Geologist	D	1	Geology and mining (drilling).
				1	Exploration, radioactive materials.
				1	Photogeology; petrology.
				1	Geochemical research (lab).
				1	Geochemical exploration.
Bolivia	3	Geologist	A	1	Engineering geology.
	1	Chemist		1	Geochemistry.
				1	Economic geology.
				1	Paleontology.
Brazil	9	Geologist	A, B	1	Stratigraphy.
	2	Cartographer		1	Vertebrate paleontology.
	1	Civil engineer		2	Geologic administration.
	5	Hydraulic engineer (SW)	A, D	1	Hydrology.
	3	Hydrogeologist	A, B	4	Natural resources surveys (hydrologic).
	1	Administrative officer		4	Natural resources surveys (minerals).
				2	Topography.
				1	Topography, cartography, geodesy.
				2	Cartography (printing).
				3	Economic geology.
				1	Structural geology, petrology, sedimentation, and so forth.
				2	Water-resources development.
				1	Minerals exploration.
				1	Ground-water exploration techniques.
British Guiana	1	Geologist	A	1	Librarianship.
	1	Geochemist		1	Mining.
	2	Chemist		2	Hydrology.
	1	Cartographer			
	1	Geophysicist			
Chile	2	Geologist	D		
Colombia	6	Geologist	A, B	3	Economic geology.
	2	Cartographer		1	Photogeology, economic geology.
	2	Chemist			
Costa Rica	3	Geologist	C, D	1	Spectroscopy.
	2	Geophysicist		1	Volcanic seismology.
Jamaica	1	Hydrogeologist	C		
Peru	2	Geologist	D		
Venezuela	1	Geologist	D		
Africa					
Dahomey	1	Geologist	C		
Ethiopia	1	Hydrogeologist	C		
Egypt (UAR)	2	Hydrologist	A	1	Ground-water hydrology.
				1	Quality of water and ground water.
				1	Minerals exploration.
Ghana	None			1	Well drilling, engineering.
				6	Well drilling.
Liberia	7	Geologist	A, B	2	Geology.
	1	Cartographer			
	1	Geophysicist			
	1	Administrative officer			
	1	Secretary			
Nigeria	3	Hydraulic engineer (SW)	A, B, C		
	1	Hydrochemist			
	6	Hydrogeologist			

See footnote at end of table.

TABLE 1.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1966*—Continued

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity[1]	Number	Field of training
Near East-South Asia					
Afghanistan	2	Hydraulic engineer (SW)	A	2	Topography.
	1	Sedimentologist		1	Cartography.
				1	Photogeology, geology mapping.
				1	Technical administration.
				1	Hydrogeology.
Cyprus	None			1	Topography.
Greece	1	Civil engineer	C		
	1	Hydrogeologist	C		
India	1	Geologist	D	1	Hydrology.
	1	Hydrologist			
Iran	1	Geologist	D	1	Geochemistry.
Jordan	1	Hydrogeologist	C	1	Hydrologic data collection.
				1	Hydrology.
				2	Well drilling (water).
				1	Hydrometry.
				1	Surface-water hydrology.
Kuwait	1	Hydrogeologist	A		
Nepal	1	Hydraulic engineer (SW)	A	2	Hydrology.
				2	Surface-water hydrology.
Pakistan	8	Geologist	A, B, C	4	Hydrology.
	1	Administrative officer		1	Geologic administration.
	4	Hydrogeologist	A, B, C, D	2	Ground-water hydrology.
				1	Geophysics.
				1	Analytical chemistry.
				1	Quality of water, ground water.
				2	Geohydrology, ground water.
Saudi Arabia	9	Geologist	A, B, C		
	4	Geophysicist			
	1	Geochemist			
	1	Geodesist			
	1	Photogrammetric engineer			
	1	Topographic engineer			
	2	Driller			
	1	Transportation officer			
	1	Electronics technician			
	1	Photographer			
	1	Administrative officer			
	1	Secretary			
	1	Chemist			
Turkey	None			1	Water-resources development.
				1	Hydrography.
				1	Photogeology.
				2	Ground-water hydrology.
				1	Electric well logging.
				1	Ground-water reports.
Far East					
Indonesia	None			1	Mining geology.
Japan	None			1	Sedimentary petrology.
				1	Isotope geology and petrology.
				1	Ash-flow tuffs.
Korea	1	Hydrologist	B	1	Geochemical exploration.
				1	Structural geology.
				1	Geophysics and geochemical exploration.
				1	Photogeology.
Philippines	2	Geologist	C, D	1	Geochemical exploration.
				1	Stratigraphy, sedimentation, petroleum geology.
				1	Ground water.
Republic of China	None			1	Surface-water hydrology.
Thailand	3	Geologist	C, D	2	Do.
	1	Driller			
Viet Nam	1	Well-logging specialist	D		

[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.

TABLE 2.—*Technical and administrative documents issued in fiscal year 1966 as a result of the U.S. Geological Survey technical-assistance program*

Country	Reports or maps prepared			
	Technical letters and administrative reports	Reports approved for publication by U.S. Geological Survey and counterparts	Reports published by outside technical journals	Reports published by U.S. Geological Survey
Australia	2			
Brazil	7	7	2	
Costa Rica	8			
Egypt	1			
Ethiopia	1			
India	2			
Indonesia		4		
Jordan	1			
Korea	1		1	
Libya			1	
Nepal			1	
Nigeria		1	1	4
Pakistan	14	16		1
Philippine Islands	4			
Saudi Arabia	50	10		
South America (other than Brazil)	1			
Thailand	3			
Tunisia			1	
Turkey			1	

SUMMARY BY COUNTRIES

BOLIVIA

Intrusives and mineralization

Joint geological investigations by the Geological Survey of Bolivia and the U.S. Geological Survey in the Quimsa Cruz mineral district southeast of La Paz, under the guidance of James Seitz, U.S. Geological Survey (USGS), and Walter Thormann, U.S. Department of State, Agency for International Development (USAID), have provided new data on the intrusives and mineralization. The principal intrusive is a batholith that has an outcrop area of about 350 square kilometers and consists of granodiorite and of granite porphyry. Pre-intrusive folds in the enclosing sedimentary rocks show little evidence of mechanical disturbance as a result of the intrusion. Base-metal deposits and associated mineralization appear to be relatively more abundant along or near the axes of the folds.

Regional geologic studies

Systematic geologic mapping under the cooperative geologic project in Bolivia, guided by Stanley Kris (USAID), has now covered a major part of the Andean region in southwestern Bolivia. This mapping has been integrated with the academic training program for Bolivian geologists and has been the principal field-training activity for the project. More than 30 geologic quadrangle maps have been published at a scale of 1:100,000. On the basis of these maps, James Seitz successfully identified and annotated geologic features in the area from Lake Titicaca southwestward to the Chilean border on one of the experimental photographs obtained from the Gemini IV spacecraft.

BRAZIL

Metallogenic provinces in Bahia

Regional geologic mapping and associated geochemical studies undertaken jointly by the Brazilian National Department of Mineral Production and the U.S. Geological Survey in the State of Bahia, Brazil, show that generalized metallogenic provinces correspond to regional geologic trends. Copper mineralization is associated with north-trending lineaments in the older Precambrian rocks, principally in the eastern part of the State. Lead is present mainly in the younger Precambrian quartzite in the northwestern corner of the area. Manganese is concentrated in the Precambrian rocks of the Minas Series in the southwestern and central part of the area, and gold, diamonds, platinum, and other heavy minerals, are in placers in alluvial deposits derived from the Lavras Series. A truck-mounted analytical laboratory, built by C. P. Ferreira, R. W. Lewis, Jr., and associates near the end of the fiscal year, should facilitate the exploration of favorable metallogenic trends, especially by geochemical testing of copper anomalies known to be associated with the Caraiba copper deposit in northern Bahia (R. W. Lewis, Jr., p. C190–C196).

Hydrologic networks and data

L. J. Snell reports that hydrologic networks, including streamflow, rainfall, and evaporation stations, were substantially expanded in northeast Brazil during the 3-year period ending December 1965 in interagency programs of the Superintendency for the Development of the Northeast (SUDENE), the National Department of Drought Control Works (DNOCS), and the Meteorological Service of the Ministry of Agriculture. At the end of this period there were in operation 101 streamflow stations, of which 3 were recording stations; 1,871 rainfall stations, of which 49 were recording stations; and 41 evaporation stations. In addition, the evaluation, computation, and compilation of a backlog of 30,000 station-years of rainfall data and 1,100 station-years of streamflow data, already collected during 1911–64 in 9 states of northeast Brazil, were completed by R. O. R. Martin. These data will be published in Brazil by the agencies concerned.

Iron

R. M. Wallace (r0366) and R. G. Reeves (r0390) have described the geology and mineral resources of the Pico de Itabirito district and the Monlevade area, respectively, in Minas Gerais. Major ore deposits of high-grade hematite are being worked, and very large reserves of high-grade ore and of lower grade concentrating ore are present.

COLOMBIA

Stratigraphic framework in Santa Marta area

Systematic geologic mapping in the Sierra Nevada de Santa Marta, northern Colombia, by geologists of the Geological Survey of Colombia with the assistance of C. M. Tschanz, has defined the stratigraphic and structural framework of this large mountain block. Metamorphic rocks more than 10,000 meters thick are overlain locally by upper Paleozoic and Mesozoic sedimentary rocks, and by Mesozoic volcanic rocks. Several large batholithic masses intrude the pre-Cretaceous formations. Recognition of the rock sequence in this isolated mountain block, which rises to 5,800 m above sea level, will facilitate interpretation of the geology of the Eastern Andes and Caribbean provinces.

Mineral discoveries in central Andes

Teams of Colombian geologists, with the guidance of L. V. Blade and Tomas Feininger, have studied several potentially significant mineral localities north and east of Medellin during systematic geologic mapping. They mapped large talc deposits and several wollastonite deposits, and found deposits of bauxite nodules and of potential expandable aggregate.

Salt and phosphorite

Detailed mapping of the Zipaquira and Nemocon salt deposits and their enclosing strata north of Bogota, by Colombian geologists with the guidance of D. H. McLaughlin, strongly suggests that additional deposits of salt are present along structural extensions of the two deposits now being exploited. Salt is now known to be present at several stratigraphic positions in the Cretaceous sequence, which is as much as 15,000 meters thick. Beds of phosphorite ⅓ to 2 m thick have been found in the region of the Bogota Plain and to the west; these deposits seem in general to be stratigraphically equivalent to the saline horizons.

COSTA RICA

Investigations of Irazú Volcano

As a result of the 1963–65 eruption of Irazú Volcano, volcanological, geophysical, and engineering geology investigations of geological phenomena and problems associated with volcanism have been undertaken by the U.S. Geological Survey under the auspices of the U.S. Agency for International Development and in cooperation with the Costa Rica Directorate of Geology, Mines, and Petroleum. These studies are intended (1) to determine the characteristics of past volcanism as a guide to future activity, (2) to establish a monitoring system, and (3) to prepare recommendations for minimizing the dangers from landslides and other effects of the eruptions.

Ash deposited by the 1963–65 eruption of Irazú Volcano was studied with reference to the fairly complete written record of phenomena observed during the eruption. As a result, criteria were developed for interpreting ash deposits in terms of mode of eruption, identification of the climatic stage, seasonal fluctuation of rainfall, and erosive action of rain and wind (K. J. Murata and others, r2050).

Three seismic monitoring stations have been installed. They will be under the direction of Rodrigo Saenz, who studied the operation of the Hawaiian Volcano Observatory and then worked with John Dietrick, of the U.S. Geological Survey, to install the seismographs in Costa Rica.

Characteristics of the terminal phase of the Irazú eruption were studied by R. D. Krushensky and G. Escalanti. Substantial ejections of fragmental materials and ash ended in February 1965, and activity virtually ceased after March 1965. Comparison of analyses of volcanic bombs from the recent eruption with analyses of lava from the last major flow (the Cervantes flow) shows very little change in composition. As a result of the recent eruptions, the main crater was substantially widened and deepened.

Geologic investigations of slope-stability conditions, landslide activity, and resultant engineering problems by H. H. Waldron, in the Reventado drainage on the south slope of Irazú, led to recommendations for ditching of slopes, planting and reseeding, channel improvement, and construction of debris, storage, and check dams. Continuing geologic studies by F. D. Spencer and R. D. Krushensky are providing data to guide further protective measures in the area.

INDONESIA

Geologic map of Indonesia

As a final product of the cooperative technical-assistance program of the Indonesian Directorate of Geology and the U.S. Geological Survey, which was sponsored by the U.S. Agency for International Development and which ended in 1965, a geologic map of Indonesia was printed for the Directorate in 1965 by the U.S. Geological Survey. The map, which shows the status of geologic information as compiled by Th. H. F. Klompé in 1954, supplemented by information available to the Directorate through 1962, is available at the Direktorat Geologi, Bandung, Indonesia, and at the U.S. Geological Survey, Washington, D.C.

Stability of damsites

Study of two proposed damsites in West Java by R. J. Anderson (p. C214–C219) has shown a variety of conditions unfavorable for engineering construction. The rocks are in part soft and weak, and in part cut by faults and susceptible to weathering. Several lines of evidence—instrumental records and oral reports of earthquakes, youthful topography little modified by erosion, and frequent landslides—suggest that the faulting is active. Work on the reservoir project has been suspended because of these conditions.

IRAN

Studies of playa deposits

Field studies in cooperation with the U.S. Air Force Cambridge Research Laboratories were conducted in the kavirs (playas) of central Iran by D. B. Krinsley. Many of the playas of Iran are remnants of Pleistocene lakes which fringed the south and east flanks of the principal mountain chains. The extensive interior playas have more complicated histories, however; they contain thin deposits of silt, clay, and salt through which Miocene rocks crop out, and appear to have been closed interior basins since Miocene time.

LIBERIA

Program of geologic assistance expanded

An expanded program of technical assistance by the U.S. Geological Survey, sponsored by the U.S. Agency for International Development, was begun in 1966 to help enlarge and strengthen the Liberian Bureau of Natural Resources and Surveys and, in cooperation with Liberian personnel, to prepare a geologic map and mineral appraisal of Liberia. The program involves the establishment of suitable work facilities for the Liberian Geological Survey; academic training of Liberian personnel in the United States, supplemented by practical field and laboratory training in Liberia; regional geological mapping at a scale of 1:250,000; and systematic reconnaissance to locate mineral showings.

LIBYA

Ground water and economic development

The continuing development of Libya will be limited by the availability of ground water, according to J. R. Jones (r0798), despite the accession of wealth from petroleum revenues. However, the usefulness of available ground-water supplies can be increased by as much as half, through improvement in techniques of ground-water development and of irrigation farming.

NIGERIA

Artesian-water supplies

William Ogilbee and H. R. Anderson, of the U.S. Geological Survey, and J. U. Uzoma and M. E. Offodile, of the Geological Survey of Nigeria, have found that the Eocene Gwandu Formation contains artesian water in an area of about 5,700 square miles in the Sokoto region of northwestern Nigeria. The most productive aquifer occurs in the basal part of the Gwandu, from which free flow can be obtained from boreholes in 3 subareas totaling about 1,000 square miles. Aquifer tests made in 11 boreholes tapping Gwandu artesian aquifers indicate coefficients of transmissibility ranging from less than 1,000 to 183,000 Imperial gallons per day per foot, and coefficients of storage ranging from 8×10^{-6} to 1.1×10^{-4}.

Investigation of the Chad Basin, in northeastern Nigeria, by R. E. Miller and R. H. Johnston, of the U.S. Geological Survey, and J. A. I. Olowu and J. U. Uzoma, of the Geological Survey of Nigeria (R.E. Miller and others, r2061; Miller and Johnston, r1172), shows that artesian water can be tapped by boreholes screened in sands of the middle zone of the Pliocene and Pleistocene Chad Formation throughout a 13,000-square-mile area of the Chad Basin. Artesian pressures in flowing boreholes range from less than 1 foot up to 70 feet above land surface. The middle-zone aquifer lies 500 to 1,250 feet below land surface and ranges from a few feet to 200 feet in thickness in the area of flowing wells. Coefficients of transmissibility computed in 3 aquifer tests of the middle-zone aquifer range from 525 to 72,500 Imperial gallons per day per foot, and storage coefficients from 1.4×10^{-5} to 1.2×10^{-4}.

PAKISTAN

Mineral exploration and development program

A program of mineral exploration and development carried out since 1956 by the Geological Survey of Pakistan and the U.S. Geological Survey under the auspices of the U.S. Agency for International Development was concluded during fiscal year 1966. The program involved a fivefold expansion in the technical staff of the Geological Survey of Pakistan, regional geologic mapping and investigation of mineral possibilities, and the preparation of a new geologic map of Pakistan. During the project, 80 technical reports were prepared for publication. About 4,400 square miles was mapped at a scale of 1: 50,000, about 14,300 at a scale of 1: 250,000, and about 137,000 in reconnaissance at smaller scales. The geological setting was determined for many deposits of iron, chromium, barium, strontium, and antimony minerals, and of coal, clay, limestone, and construction materials. New facilities for the Pakistan Survey were established and put into operation, including photogrammetry, paleontology, mineralogy, electronics, cartographic, and photographic laboratories.

Ground-water hydrology of the Punjab

D. W. Greenman, W. V. Swarzenski, and G. D. Bennett,[42] of the U.S. Geological Survey, report that leakage from canal systems, some more than 100 years old, is the principal cause of rising ground-water levels and of consequent waterlogging and land-salinization problems. Geologic studies have shown that virtually the entire Punjab is underlain to depths of 1,000 feet or more by unconsolidated alluvium, which is saturated almost to the land surface. Moreover, large-capacity wells yielding 4 cubic feet per second or more can be developed almost everywhere. Beneath about two-thirds of the Punjab, the alluvium is saturated to a depth of 500 feet or more with water of chemical quality (less than 1,000 parts per million of total dissolved solids) acceptable for irrigation. Usable ground water in storage in the alluvial aquifer is on the order of 2 billion acre-feet. On the basis of the findings of the hydrologic investigation a long-range program for reclaiming the irrigated lands of the Punjab has been prepared by West Pakistan's Water and Power Development Authority. This program is based on networks of tube-wells spaced with an average density of one per square mile. The ground-water withdrawals will serve the dual purpose of helping to supply requirements of water for irrigation as well as providing subsurface drainage.

According to G. D. Bennett, Ata-urRehman, Ijaz Ahmed Sheikh, and Sabir Ali,[43] 141 aquifer tests in the Punjab Plain of West Pakistan indicate that lateral permeabilities of the alluvial aquifer are predominantly in the range from 0.001 to 0.006 cubic feet per second per square foot and average 0.0032 cfs per sq ft. Vertical permeabilities are in the range from 10^{-5} to 10^{-3} cfs per sq ft. Specific yields generally lie in the range from 0.02 to 0.26, and average 0.14.

Summaries of mineral-resource studies

R. G. Schmidt has summarized the results of radioactive mineral investigations in Pakistan during the period 1952 to 1962 in a paper entitled "Summary of the search for radioactive minerals in Pakistan," prepared for publication by the Geological Survey of Pakistan. Radioactivity determinations and analytical results are presented for all the classes of epigenetic and syngenetic deposits investigated. The most promising radioactive deposits are in the middle part of the Siwalik Group of late Tertiary age near Dera Ghazi Khan, West Pakistan, where small pockets of uranium-vanadium minerals, scattered over a distance of at least 35 miles, have been found in a sandstone unit.

S. A. Stanin and others, in a report prepared for the Geological Survey of Pakistan, have summarized and evaluated studies of aluminous minerals to date. These studies have been made mostly by personnel of the Geological Survey of Pakistan of deposits of aluminous claystone, or laterite, at the base of the Eocene sequence over large areas in the Sulaiman Mountains along the west side of the Indus River and in the frontal ranges of the Himalayan Mountains in West Pakistan. The paper, entitled "Laterite and other aluminous deposits in West Pakistan," contains an index to all known localities. Some of the deposits may have potential as a source of aluminum, and some may be a potential source of iron, but because of complex mineralogy, abrupt lateral changes in composition and thickness, complicated structure, and difficult access, much careful and detailed study is still required to assess the economic possibilities of these deposits.

Devonian laterite

A fossil laterite reported by K. W. Stauffer at the base of an Upper Devonian dolomite unit near the village of Kuragh, in Chitral State in northern

[42] D. W. Greenman, W. V. Swarzenski, and G. D. Bennett, in press, Ground-water hydrology of the Punjab, West Pakistan: U.S. Geol. Survey Water-Supply Paper 1608-H.

[43] G. D. Bennett, Ata-ur-Rahman, Ijaz Ahmed Sheikh, and Sabir Ali, in press, Analysis of aquifer tests in the Punjab region of West Pakistan: U.S. Geol. Survey Water-Supply Paper 1608-G.

West Pakistan, is one of the few recorded laterites from Paleozoic rocks. The thickness of the laterite averages 5 to 10 feet. The mineral constituents of a sample of the laterite, determined by X-ray, are hematite, chamosite(?), boehmite, and diaspore, with small amounts of anatase, rutile, pyrophyllite, and kaolinite.

Regional stratigraphic correlation

Stratigraphic correlation of the Carboniferous to Tertiary sequence of rocks has been extended along the frontal ranges of the Himalayan Mountains from the Kohat area, near Peshawar, northeastward for 100 miles through the Kala Chitta Hills to the Hazara area. Equivalent rock formations, as worked out in the three widely separated areas by A. N. Fatmi, Geological Survey of Pakistan, and J. A. Calkins and C. R. Meissner, U.S. Geological Survey, provide stratigraphic control from near the Afghan border to western Kashmir. This correlation is the basis for geologic interpretations in a series of quadrangle maps and reports prepared for publication by the Geological Survey of Pakistan.

Stratigraphic and structural elements along Afghan border

Stratigraphic and structural features of the Parachinar quadrangle, along the Afghanistan border west of Peshawar, are described by C. R. Meissner, U.S. Geological Survey, and Muzaffar Husain, M. A. Rashid, and U. B. Sethi, Geological Survey of Pakistan, in a report entitled "Stratigraphy of the Parachinar quadrangle, West Pakistan." The area is structurally one of the most complex in West Pakistan. The Cretaceous rocks present two facies, an easterly quartzite-sandstone-limestone sequence, and a westerly shale-mudstone-siltstone-shaly limestone sequence. The only contact found between these facies is a low-angle thrust fault, along which the rocks of the western sequence are believed to have moved over those of the eastern sequence. Near its frontal edge the thrust plate was later folded.

PHILIPPINE ISLANDS

1965 eruption of Taal Volcano

Taal Volcano, 60 kilometers south of Manila, erupted violently on September 28, 1965. The effects of the eruption were studied jointly by J. G. Moore, of the U.S. Geological Survey, Kazuaki Nakamura, of the University of Tokyo Earthquake Research Institute, and Arturo Alcaraz, of the Philippine Commission on Volcanology, under the auspices of the Philippine Commission on Volcanology, headed by Elpidio C. Vera, and the U.S. Agency for International Development. Because more than 30,000 residents of the volcano area had been evacuated, the immediate problem was to evaluate the character and extent of the eruption in order to assess the possibility of more activity and to delineate the danger zone. Within about 1 week after activity ceased, most of these people were permitted to return to their homes or were relocated elsewhere, but it was recommended that Volcano Island and the devastated area on the west shore of Lake Taal remain permanently an evacuated danger area.

The study showed (J. G. Moore and others, r0750) that the eruption was apparently caused by the access of water from Lake Taal to basalt magma that was being intruded upward at shallow depth in the west flank of Volcano Island. The resultant steam explosions opened a new crater 1.5 km long and 0.3 km wide. The new explosion crater, as deep as 50 meters below lake level, contains a new inlet of Lake Taal where previously there was tropical farmland. Ninety million cubic meters of rock was blasted out of the crater and about 60 sq km was covered with an ash blanket more than 25 centimeters thick. More than 190 people were killed by the eruption.

Clouds that formed during the multiple explosive eruptions rose to heights of 15 to 20 km and deposited fine ash as far as 80 km west of the vent, in the direction of the prevailing winds. At the base of the main explosion column, flat turbulent clouds spread horizontally with hurricane velocity, transporting ash, mud, lapilli, and blocks.

These horizontally moving, debris-laden clouds are very similar to the base surge produced during shallow nuclear explosions. The clouds were highly abrasive because of suspended rock fragments, and shattered and obliterated all trees within 1 km of the explosion center and sandblasted objects more than 5 km distant. In much of the area traversed by these clouds, layers of mud as much as 40 cm thick were deposited on vertical surfaces facing the explosion center. Myriad giant ripple marks or dunes measuring 3 to 15 m from crest to crest were produced throughout a zone extending 2.5 km from the explosion center. Dune crests are oriented at right angles to the direction of movement, and the wavelength of the dunes decreases systematically outward from the explosion center.

Comparison of the distance traveled and the apparent velocity of these clouds with those of base surges produced by nuclear-explosion tests permits estimation of the force of the steam explosions at Taal Volcano. Preliminary study indicates that each of the large debris-laden clouds (of which there were many) was produced by an explosive force equivalent to between 20 and 100 kilotons of high explosives.

R. M. Moxham, working with the U.S. 13th Air Force, obtained aerial infrared images of the volcano area on October 18–21, 1965. From the images a thermal map was prepared which delineates concentric and radial fractures and rift systems, both old and new. Infrared techniques, which permit rapid location of areas of abnormal heating, will be useful in determining and evaluating many of the future thermal changes in the volcano.

Growth of Philippine Bureau of Mines

In December 1965 the U.S. Geological Survey completed 19 years of assistance to the Philippine Bureau of Mines under the auspices of the International Cooperation Administration and the Agency for International Development, U.S. Department of State. The Bureau was established in 1936 but was disrupted by World War II, which destroyed the Philippine mining industry almost completely. Since 1945, the Philippine mining industry has grown from almost no mineral production to an annual gross mineral product of nearly $125 million by 1965, representing about 8 percent of foreign-exchange earnings. The mining industry now employs more than 36,000 persons. In the decade 1955–64 alone, cumulative mineral production value was about $725 million (P 2,829 million); it increased by 318 percent from 1955 to 1964.

The Philippine Bureau of Mines now numbers more than 500 employees, 71 of whom have received advanced scientific training under the U.S. Geological Survey's technical-assistance program. Field and laboratory equipment have been provided sufficient to establish at least limited capability in diverse operations of the Bureau. The program has already resulted in 67 papers jointly published by U.S. Geological Survey and Philippine Bureau of Mines authors, many additional papers solely by Bureau authors but concerned with joint projects, and numerous open-file reports. Major commodity surveys have encompassed coal, cement and ceramic raw materials, copper, manganese, nickel, chromite, and iron. In 1964, the joint project culminated with the publication of the first complete and colored geologic map of the Philippines, at a scale of 1:1,000,000.

Highlights of the mineral-development program were the detailed evaluation of unmined nickel laterites in northeastern Mindanao and the discovery of a commercial chromite ore body in Zambales province, Luzon. The copper industry has grown vigorously. In prewar days, gold was the unchallenged leader of the mining industry, but now copper leads the metal-mining industry with the annual production in 1964 of more than $35 million, compared to about $20 million for precious-metal production. Ore bodies have now been proved which will more than double the current copper production.

Geologic mapping of three iron-copper mineralized areas by geologists of the Bureau of Mines, with the assistance of L. E. Andrews, suggests that structural and stratigraphic control of diorite intrusions was similar in the three areas. At Santa Ines and possibly at Dulangan, the ascent of the magma was apparently controlled by calcareous beds in the troughs of deeply plunging, faulted synclines.

SAUDI ARABIA

Pyrite

W. C. Overstreet, W. E. Davis, and R. V. Allen report that pyrite underlies an extensive gossan at Wadi Wassat in southwestern Saudi Arabia. The gossan is 200 to 1,000 meters wide and 17 kilometers long, and in 3 drill holes at the northern end of the deposit its thickness ranges from 25 to 40 m. The underlying pyrite occurs in zones which are nearly vertical. Some zones of massive pyrite are at least 20 m thick, and some, rich in disseminated pyrite, are at least 60 m thick. The pyrite is in Precambrian layered rocks, dominantly andesite, graywacke, and marble, in a roof pendant between composite plutons of diorite and granite.

Analyses of major elements in 10 samples of gossan from the northern end of the deposits, made by the Ministry of Petroleum and Mineral Resources in Jiddah, show the following: Fe, 25 to 31 percent; SiO_2, 9 to 30 percent; S, 1 to 11 percent; Al_2O_3, up to 10 percent; CaO, 4 to 19 percent; and P, variable. The results of minor-element analyses by C. E. Thompson, of the U.S. Geological Survey, show small variations which suggest the potential value of geochemical exploration of the deposit. Analyses of the major elements in the pyrite have not been completed.

Exploratory electromagnetic surveys over the gossan in the Wadi Wassat area indicate that the massive pyrite found by drilling in the northern part probably is repeated intermittently throughout the length of the gossan (approximately 17 km). The richest part of the pyrite-bearing zone is inferred to lie in the northern part of the area. Geophysical evidence suggests that the zone dips steeply west and is covered by less than 65 m of weathered material. Within this zone, massive pyrite probably occurs as lenses and irregular bodies which in places form multiple subsurface conductors as indicated by prominent electromagnetic dip angles.

Preliminary results of the studies suggest that several million tons of pyrite is present beneath the gossan to a depth of 200 m; probably the entire deposit contains more than 500 million tons of pyrite.

Unusual jasperoid in barite veins

D. A. Brobst (p. C187–C189) reports finding anomalous concentrations of trace elements in jasperoid from barite veins near Rabigh, about 150 miles north of Jiddah, Saudi Arabia. The trace elements found include Be, Pb, Y, B, Mn, and Fe. This finding suggests the possible presence in the area of potentially valuable hydrothermal ore deposits.

Control of ore mineralization

Ore mineralization at the ancient mining site of Samrah, in the east-central part of the Arabian Shield, is shown by study of ancient mine workings and by geochemical data to have been controlled by fracture patterns. The country rock in the Samrah area is igneous, ranging from gabbro to pegmatite and dacite. The structural fabric of the area is dominated by faults; extensive fracturing was associated with the faulting. The economic minerals were deposited in open fractures adjacent to constrictions where these fractures pass through a zone hardened by the repeat sealing of old fractures. Use of this interpretation near Samrah led to the location of a number of ancient prospecting sites at the intersections of fractures, which can be recognized on aerial photographs at a scale of 1: 60,000. P. K. Theobald, Jr., concludes that the mining site, formerly a source of native silver, deserves detailed exploration for silver and lead. On the basis of his conclusions and of earlier work by R. G. Bogue and H. A. Quinn, H. D. Horn of the U.S. Geological Survey sank a diamond-drill hole on the Samrah workings. Samples from the core contained as much as 139 ounces/ton of silver and 38.4 percent of lead.

Alluvial concentrations of molybdenum, tin, and tungsten minerals

The presence of molybdenum, tin, and tungsten minerals in alluvium in the Najd quadrangle, in the eastern part of the Arabian Shield, suggests that this area is in a district of high-temperature mineralization. The first occurrences in Saudi Arabia of molybdenite and of what is probably cassiterite are reported by J. W. Whitlow from areas anomalously rich in tungsten. Samples of wadi sand, and heavy-mineral concentrates from the sand, contain from 500 to 1,000 ppm of tin and 700 to 10,000 ppm of tungsten; locally molybdenite, beryl, and scheelite are megascopically visible. Scheelite, however, is not the principal tungsten mineral in the sand and concentrates. Samples richest in tungsten contain one of the members of the huebnerite-ferberite group of tungstate minerals. Tin-rich samples probably contain cassiterite. The tin, molybdenum, beryllium, and tungsten minerals seem to be related to upper Precambrian granitic rocks which also have regionally positive anomalous quantities of zinc and niobium. Elsewhere in Saudi Arabia the late zinc- and niobium-rich granitic rocks appear to be part of the peralkalic differentiation series. Contact zones between the intrusive granite and sequences of metasedimentary rocks are favorable loci for deposition of the characteristic high-temperature minerals of the district, as are pegmatite (molybdenite, particularly), quartz veins (beryl and tungsten minerals), and silicified brecciated granite (tungsten and molybdenum).

Magnetite mineralization

Massive magnetite deposits possess the greatest mineral potential found during a reconnaissance mineral survey of Precambrian rocks exposed in parts of the Hijaz and Wadi Ar Rimah quadrangles, in north-central Saudi Arabia. According to C. L. Hummel, mineral occurrences and deposits of epigenetic, syngenetic, and metamorphic origin were found. Two periods of hydrothermal mineralization are represented. Deposits of the first period are along the contacts of granitic masses; those of the second are along later wrench faults and associated structures. The magnetite is in small massive bodies in marble beds, along and near the margins of the granites. The magnetite deposits found are too small to be of economic importance, but they represent processes which may have formed larger deposits.

Results of a magnetometer investigation in the southern part of the Jabel Idsas magnetite area, in east-central Saudi Arabia, are reported by W. E. Davis and R. V. Allen to indicate that a zone of magnetite more than 1,700 meters long lies beneath southward-protruding ridges and the adjoining margin of a wadi in the central part of the area. A small zone of lesser economic importance occurs beneath a low ridge to the east. Within these zones, the magnetite probably occurs as lenticular masses, stringers, and veins. The main zone averages about 75 m in width, and it may contain as much as 50 percent magnetite.

Mineralization in gold-quartz veins

Seven small abandoned, ancient gold mines, in the Precambrian shield between Wadi Ar Rimah on the north and lat 24°30′ N. on the south, and between meridians 42° and 43° E., were observed by J. W. Mytton to contain stibnite locally. In the southwestern part of the area A. O. Ankary reported moderately abundant wolframite in quartz veins in the vicinity of ancient gold mines, and farther west C. L. Hummel and others observed scheelite with gold-quartz veins. The mineralized area requires further examination. Assay reports in the files of the Directorate General of Mineral Resources also show that grab samples from the veins and from dump material locally contain as much as 2.32 ounces/ton of gold, 5.84 oz/ton of silver, and a small amount of lead.

Silver-copper-zinc mineralization

One diamond core-drill hole at the ancient Lahuf mine in the west-central part of the Precambrian shield is reported by P. K. Theobald, Jr., C. E. Thompson, and Louis Gonzalez to show a main mineralized zone 17 feet thick averaging 0.4 ounces/ton silver, 1.2 percent copper, and 1.6 percent zinc. A 4-foot section at the beginning of the main mineralized zone contains 0.9 oz/ton silver, 2.6 percent copper, and 1.8 percent zinc. The zone is a highly mineralized, quartz-sealed breccia and quartz-vein system striking N. 53° W. and dipping nearly vertically through the ancient workings. The country rock consists of fine-grained altered diorite, altered porphyritic diorite, and altered diorite porphyry.

Spectrographic analyses made on all core samples for 27 elements provide continuous geochemical control through the interval cored. Silver, copper, and zinc are the only elements of this group that are of potential economic value. The distribution of these three elements is directly related to the distribution of vein types, and particularly of the latest, quartz-rich, veins.

THAILAND

Mineral studies in northeastern Thailand

The U.S. Geological Survey completed a 3½-year investigation of mineral potential of part of the Mekong River basin of northeast Thailand at the request of the United Nations Mekong Project Committee and the U.N. Special Fund. Fifty-eight mineral prospects, including 34 new discoveries, were examined in a joint project with the Royal Thai Department of Mineral Resources and in cooperation with the United Kingdom Overseas Geological Survey. Most of the mineral prospects examined are in the Loei-Chiengkarn area in north-central Thailand, where several granodiorite stocks intrude a sequence of sedimentary, volcanic, and regionally metamorphosed rocks. Most of the iron and base-metal prospects were emplaced in volcanic rocks, especially tuffs, and are related to intrusive contacts.

Seventeen iron prospects were investigated. Diamond drilling of two deposits has revealed combined reserves of all categories of about 24 million tons of iron ore. In one of these the leached hematite-magnetite surface zone contains about 62 percent total iron, and the unweathered subsurface zone of magnetite-pyrite contains about 46 percent total iron. These deposits are in part amenable to open-pit mining and to concentration by magnetic methods. Chances for additional tonnages at these two deposits are limited. Four base-metal prospects, among 20 studied, were found to have sulfide mineralization or promising geochemical and geophysical anomalies. Two of the prospects contain lead-zinc minerals in limestone associated with intrusive contacts; the other two are copper prospects in volcanic rocks. At Chaiyaphum, about a hundred miles south-southeast of the Loei-Chiengkarn area, a bedded salt deposit that is nearly horizontal and is 103 meters thick was intersected 61 m below the surface. More than 500 million tons of crude salt, averaging 96.7 percent NaCl, was inferred by drilling; additional reserves estimated at several billion tons are anticipated.

Summary reports on salt and lignite

Two papers resulting from the former assistance program of the U.S. Geological Survey and the U.S. Agency for International Development were transmitted to the Royal Thai Department of Mineral Resources for publication. "Salt resources of Thailand," by L. S. Gardner, H. F. Haworth, and P. N. Chiangmai, contains a comprehensive review of the geology and potential salt resources of Korat Plateau of Northeast Thailand. Probably 40,000 square kilometers is underlain by salt-bearing rocks of Mesozoic age. Salt resources within an area of only 8,000 sq km comprise 1.3 billion tons of measured reserves, 4.7 billion tons of indicated reserves, and 2,700 billion tons of inferred reserves.

More than 112 million metric tons of lignite, representing measured, indicated, and inferred reserves, is available in one deposit now being mined in Thailand, according to a report entitled "The Mae Mo lignite deposit in northwestern Thailand," by L. S. Gardner. The report describes 2 lignite beds, each as much as 30 meters thick, separated by 30 m of claystone. Much of the lignite has a calorific value equal to that of subbituminous coal.

TUNISIA

Ground-water development

V. C. Fishel (r1089) has recently summarized the history of the development of ground water in Tunisia. He points out that ground water has been used for municipal supplies for thousands of years, citing the example of the aqueduct built by the Romans about 2,000 years ago to carry water from the springs of Zaghouan to supply Tunis and Carthage. More recently, emphasis has been given to drilling deep wells equipped with turbine pumps. Most of these wells tap aquifers in alluvial deposits of the major river valleys and in deposits of Miocene age underlying the plains of central and southern Tunisia. A pilot groundwater development program proposed by H. E. Thomas and L. C. Dutcher, begun in November 1964, was completed during 1966. It involves the construction of 50 production wells in central Tunisia, to provide training in new well-drilling and development techniques as well as to obtain ground water for intensive irrigation of about 3,400 acres of land not presently irrigated.

TURKEY

Strontium-bearing todorokite

A. S. Radtke and L. M. Jones (p. C158–C161) have analyzed and discussed a todorokite from Soganliyürük in northwest Turkey. The specimens are notable for their unusual content of strontium. The approximate formula of the todorokite is:

$$(Ca, Sr, Mn^{+2}, Mg, Ba, Na_2)\ (Mn^{+4})_6O_{12}\cdot 3H_2O.$$

REGIONAL STUDIES OF FERTILIZER MINERALS

Two broad studies of resources of fertilizer minerals were made by the U.S. Geological Survey during 1966, one in South America and the other in the Eastern Hemisphere.

Fertilizer resources of South America

J. F. Harrington, D. E. Ward, and V. E. McKelvey find that although the production of fertilizer minerals in South America is small, relative to requirements, the continent has the potential resources to meet its present needs and to support a much wider use of mineral fertilizer. The study, made at the request of the U.S. Agency for International Development, shows that prospects are good for increased and more widely distributed discovery and production of phosphate. Potash resources also have considerable potential, although prospects for wide occurrence are less favorable than those for phosphate. Potential resources of sulfur are both large and widely distributed.

Exploration for phosphate in the Eastern Hemisphere

R. P. Sheldon studied the phosphate potential in seven countries—Iran, Saudi Arabia, Pakistan, India, Thailand, the Philippines, and Australia. The work was intended both to locate phosphatic horizons and to demonstrate to counterpart agencies new techniques of phosphate exploration.[44 45] The study was made in cooperation with the geological survey or mineral-resources agency of each country visited. It was sponsored by the governments of Saudi Arabia and Australia, by the U.S. Agency for International Development, and by the United Nations Special Fund.

Phosphate deposits have long been known in Middle Eastern countries, including Israel, Jordan, Lebanon, Syria, and Iraq, at the eastern end of the North African–Middle Eastern phosphogenic province, in deposits of the Tethys Sea of Cretaceous to Tertiary age. In 1962, Cretaceous phosphate deposits were found in Turkey,[45] and in 1963, Eocene phosphate deposits were found by geologists of the Iranian Geological Survey (D. A. Andrews, written commun., 1964). Similar rocks which may contain phosphate extend into Saudi Arabia, Pakistan, and India, and these rocks were explored during the study.

The Eocene phosphorite previously discovered in the Pabdeh Formation in Iran is thin, lenticular, and of low grade. However, study of oil-well logs from the Persian Gulf and the Khuzistan Plain suggests that phosphate occurs in the Cretaceous Kazhdumi and Gadvan Formations, despite the fact that phosphate has not been found in outcropping rocks of the same age in the Zagros Mountains.

Sheldon's investigation in Saudi Arabia revealed the presence of phosphorite of Paleocene and Eocene age in the Hibr Formation, near Turayf in the northern part of the country. In additional studies J. W. Mytton found four phosphate-rock deposits, also in northern Saudi Arabia. All these deposits are near well-developed lines of communication—the Trans-Arabian pipeline or existing highways—and the potential resources in these relatively accessible deposits are large.

Studies of the Cretaceous and Tertiary rocks of Pakistan and India revealed that they were either shallow-

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[44] V. E. McKelvey, 1963, Successful new techniques in prospecting for phosphate deposits: Science, Technology, and Development, United States papers prepared for the United Nations conference on the application of science and technology for the benefit of less developed areas, v. 2, p. 163–172.
R. P. Sheldom, 1964, Paleolatitudinal and paleogeographic distribution of phosphorite, *in* Geological Survey Research 1964: U.S. Geol. Survey Prof. Paper 501–C, p. C106–C113.
[45] R. P. Sheldon, 1964, Exploration for phosphorite in Turkey—A case history: Econ. Geology, v. 59, p. 1159–1175.

water marine to nonmarine sedimentary rocks or rapidly deposited flysch, and that they are not likely to contain phosphate deposits. Thus, the eastern terminus of the North African-Middle East Cretaceous and Tertiary phosphogenic province may be in the Persian Gulf and Iran. However, Sheldon found an 8-foot bed of low-grade phosphorite in Jurassic rocks in the Himalayan foothills in India, in a section in which a 6-inch phosphate deposit had previously been known. The presence of these deposits suggests that in the Himalayas the phosphogenic province related to the Tethys Sea may extend stratigraphically downward into the Jurassic System. In addition, two zones of phosphatic material have been found in Cretaceous rocks, and one in Jurassic rocks, near the village of Nizampur in northern West Pakistan. The upper zone consists of a 2-foot bed of nodular, conglomeratic limestone containing 10 to 15 percent P_2O_5. The middle zone is a thin-bedded, glauconitic, calcareous sandstone with an average thickness of 55 feet, generally containing less than 5 percent P_2O_5, but locally as much as 12 percent P_2O_5. The lower zone is 10 to 15 feet of gray shale and glauconitic sandstone with phosphatic nodules. Channel samples of this zone contain 5 to 15 percent P_2O_5.

The Cambrian and Ordovician phosphate deposits of North Viet Nam, known since before World War II, have been the only deposits of significance known in southern Asia. Studies in northwestern India resulted in the discovery of a pre-Permian phosphorite deposit southwest of Jaiselmer. This occurrence, which offers considerable economic potential, suggests that the lower Paleozoic phosphogenic province of southern Asia is widespread, because it is possible that the phosphorites in the India deposit and in North Viet Nam are related both in age and in basin of deposition. Much more work needs to be done. A part of this needed work was pointed out by the studies made in Thailand, where the Thung Song Formation of Ordovician age in peninsular Thailand is reported to contain beds of chert and black shale and may contain phosphorite. Further, phosphorite has been found in Devonian black shale in the Elburz Range by Messrs. Samimi and Movahed of the Geological Survey of Iran. This bed is of medium grade and apparently has a high alumina content; it is 2 meters thick, extends for many kilometers, and offers some economic potential. It is being further studied by the Iranian Geological Survey. The regional geological significance of this deposit is difficult to assess with present knowledge, but perhaps it belongs to the Paleozoic phosphogenic province of southern Asia.

No discoveries nor favorable indications of phosphate were found during a reconnaissance of the Philippines. The Mesozoic and Tertiary geologic history of the Philippines was dominated by mobile-belt tectonics and volcanism, and sedimentation was rapid. Probably there were neither time for phosphate deposits to form nor cold upwelling marine currents; the only chemical sediments found are warm-water coralline limestone.

No economically significant marine phosphorite is known to occur in Australia, but small lower Paleozoic deposits have been known for some time in the Tasman geosyncline of eastern Australia, and others have been found recently by private industry. These deposits appear to have been formed in a marine upwelling-current environment, and offer some encouragement that commercial deposits will eventually be found.

INVESTIGATIONS OF PRINCIPLES AND PROCESSES

A substantial part of the Geological Survey research program is primarily topical and involves the application of principles and analytical techniques largely developed in the laboratory to the elucidation of the evolution, composition, and structure of: (1) the earth as a whole, (2) its rocks and minerals, (3) its constituent elements, (4) its waters, and (5) its past and present living forms. The emphasis is upon quantitative measurements as a means of obtaining basic data having genetic significance. For the past several years the scope of the topical studies has been broadened to include investigations of the Moon and of materials of extraterrestrial origin under sponsorship of the National Aeronautics and Space Administration.

The program of topical studies is, by its nature, long term, but it has produced important current benefits. For example, the program has played an integral part in setting up and operating a nationwide nuclear-blast and earthquake detection system, together with the volcano-eruption warning system for the island of Hawaii. Studies of the stability relations and isotopic compositions of minerals have given insight into the ore-forming processes and have provided new guides for finding ore. Many new analytical techniques and methods of wide application, within the Geological Survey and without, have been developed in the fields of wet chemistry, emission spectroscopy, mineralogy, X-ray spectrometry, and the electron microprobe. Analytical services in these fields and in the fields of paleontology and geochronology are provided for the Geological Survey as a whole.

PALEONTOLOGY

Research by paleontologists of the U.S. Geological Survey involves biostratigraphic, 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 and to application of the mapping to synthesis of the geologic history of North America and the surrounding oceans. Significant results of paleontologic research attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area.

PALEOZOIC OF THE EASTERN STATES

Erect land plants in Lower Silurian of Maine

J. M. Schopf, U.S. Geological Survey, Ely Mencher, Massachusetts Institute of Technology, A. J. Boucot, California Institute of Technology, and H. N. Andrews, University of Connecticut, (p. D69–D75) have described small, erect plant axes from Lower Silurian rocks in northern Maine. The fossils contain an outer layer which evidently represents mechanical tissue that provided for erect posture. No trace of vascular tissue has been found. The fossils may represent a primitive type of land plant in which the mechanical function of cortical tissure was more advanced than the conductive specialization by vascular tissue.

Baltic ostracodes from Maine

Ostracodes from the Silurian formations in the Eastport quadrangle, Maine, have proved to be more closely related to ostracodes from the Baltic faunal province than to those from the Appalachian province in western Maine, according to J. M. Berdan. In particular, the Pembroke Formation contains the ostracodes *Hemsiella* sp. aff. *H. maccoyana* (Jones), *Macrypsilon* sp. aff. *M. salterianum* (Jones), *Sleia* sp. and *Londinia* sp. aff. *L. arisaigensis* Copeland, which are close to species in the Stonehouse Formation of Nova Scotia and the "Beyrichien-kalk" of the Baltic area. These formations are considered latest Silurian to possibly earliest Devonian in age. Therefore, it appears that the Pembroke and overlying Eastport Formations are somewhat younger than has been thought hitherto.

Fayetteville ostracodes restudied

Restudy by I. G. Sohn of ostracodes from the Fayetteville Shale of Arkansas, described originally by G. H. Girty in 1910, has disclosed a more varied fauna than Girty recognized. Acetate serial peels and microdissection of carapaces of *Glyptopleura inopinata* Girty, the type species of *Glyptopleura*, show a peculiar kind of hinge structure, previously postulated by Sohn in 1949. This structure will aid in understanding the relationships of this genus with other Paleozoic straight-backed ostracode genera.

Growth study of Devonian coral genus

W. A. Oliver, Jr., has shown that colonies of the Devonian tabulate coral *Striatopora flexuosa* Hall are composed of two morphologically distinct types of corallites that budded alternately. One type represents accelerated growth of the polyp which did not reproduce within the colony. The other type grew more slowly, and reproduced both types of individuals asexually. This kind of dimorphism and alternation of asexual generations has not been known previously in Paleozoic corals.

Revision of conodont types

Type specimens used by Ulrich and Bassler[46] in their classic study of conodonts from New York, Tennessee, and Alabama have been prepared, rephotographed, and redescribed by J. W. Huddle in order to clarify the definitions of several genera and species. Many species have been placed in synonymy. This study is fundamental to a general revision of conodont taxonomy and a reinterpretation of biostratigraphic zonation of the Upper Devonian.

Mississippian occurrence of *Chaetetes*

Chaetetes, a hydrozoan commonly regarded as a guide fossil to Lower and Middle Pennsylvanian rocks in North America, has been identified for the first time from the American Mississippian by Helen Duncan. The specimens were collected by Benjamin Gildersleeve from middle Chester rocks in Logan County, Ky. This species of *Chaetetes* is similar to one described from the upper part of the Lower Carboniferous of England and Russia.

Kentucky Ordovician fossils

Two phases of the reevaluation of Middle Ordovician fossils from Kentucky are well advanced. Research on brachiopods from the Lexington Limestone by R. B. Neuman has resulted in a revision of the dalmanellids, most of which are now properly assigned to *Dalmanella*, not to *Onniella*. Study of the trilobites by R. J. Ross, Jr., reveals that most of the calymenid forms from Kentucky represent the genus *Gravicalymene*. Reference collections from the Trenton group at Trenton Falls, N.Y., also include a species of *Gravicalymene*, hitherto unreported from North America, and Ross has discovered that three species from Michigan, previously assigned to *Flexicalymene*, properly belong in *Gravicalymene*. These discoveries will assist in biostratigraphic interpretations and correlations of the Kentucky Ordovician.

Studies by O. L. Karklins of bryozoans from the reference section of the recently redefined Lexington Limestone near Frankfort, Ky. (D. F. B. Black, E. R. Cressman, and W. C. MacQuown, Jr., r1882, p. C11–C14), indicate that the greater part of the Lexington Limestone is Barneveld in age.[47] Changes in the bryozoan assemblage near the top of the Lexington are to be studied further because of their bearing on the boundary between Middle and Upper Ordovician rocks. Karklins found that several species, including some assigned to *Prasopora*, *Hallopora*, and *Hemiphragma*, may be suitable for delimiting biostratigraphic zones.

Algal stromatolites in Tennessee

L. D. Harris (p. C48–C53) has found that about 60 percent of the Upper Cambrian Copper Ridge Dolomite, in Union and Claiborne Counties in northeastern Tennessee, is made up of algal stromatolitic structures. Two forms of the structures are recognized; one consists of vertically stacked hemispheroids in vuggy crystalline dolomite, and the other of laterally linked hemispheroids in silty to finely crystalline dolomite. Persistence of porous stromatolite zones in the subsurface, inferred from drill cuttings, suggests that these structures may be potential sites for the accumulation of petroleum.

PALEOZOIC OF THE WESTERN STATES

Cambrian trilobites from Alaska

Cambrian rocks near the boundary between Alaska and Yukon Territory include 11 distinct trilobite faunas in two strongly contrasting contemporaneous lithofacies, according to A. R. Palmer. On the international boundary, clean carbonate rocks throughout the Cambrian seem to indicate the persistence of a large carbonate bank. Along the Yukon and Tatonduk Rivers, a few miles to the west, contemporaneous rocks comprise three formations: a lower massive, dominantly clean carbonate-rock formation; a middle argillaceous formation; and an upper formation composed of silty and in many places cherty, thin-bedded limestones interbedded with edgewise limestone conglomerates and containing a basal limestone boulder conglomerate. Lateral variations of thickness and petrography of the upper formation are striking. Trilobites of Early, Middle, and Late Cambrian ages

[46] E. O. Ulrich and R. S. Bassler, 1926, A classification of the toothlike fossils, conodonts, with descriptions of American Devonian and Mississippian species: U.S. Natl. Mus. Proc., v. 68, art. 12, 63 p.

[47] D. W. Fisher, 1962, Correlation of the Ordovician rocks in New York State: New York State Mus. and Sci. Service, Geol. Survey, Map and Chart Ser., no. 3.

occur in the upper formation, which seems to represent a deeper marine environment in which talus from the carbonate bank to the east was accumulated. Faunas of several ages show strong Asiatic affinities. Their association with trilobites that seem to comprise characteristic North American peripheral faunal facies emphasizes the probability of close geographic ties between Asia and northwestern North America during Cambrian time.

Cambrian paleogeography of Great Basin

Analysis of Cambrian sedimentary patterns and paleogeography by A. R. Palmer, through the preparation of more than 20 paleofacies maps for times of maximum expansion and contraction of areas of carbonate sedimentation, shows the presence of a major positive area to the west of central Idaho throughout the Cambrian. Carbonate sediments formed a continuous belt from Canada to Mexico, between inner and outer detrital sequences, only during periods of maximum expansion of carbonate sedimentation.

Facies changes in Eureka Quartzite

R. J. Ross, Jr., has delineated an abrupt change within the miogeosynclinal facies that includes the Ordovician Eureka Quartzite in central Nevada. The unit and its correlatives are different on opposite sides of a line running from Cortez, Nev., south-southeastward to the west of Lone Mountain and through Fenstermacher Wash between the Fish Creek and Antelope Ranges. Because the stratigraphy of the Eureka Quartzite is so different on opposite sides of this line, Ross concludes that the Antelope and Fish Creek Ranges could not have been originally adjacent to one another.

Devonian of central Nevada

A thick sequence of sandstones and shales with lenticular reefy limestone bodies, in the Fish Creek Range, extends northward toward the Eureka mining district, Nevada. Several of the isolated limestone bodies which are alined northerly through the Cockalorum Wash quadrangle yield coral faunas with *Hexagonaria*, *Peripaedium*, and *Heliolites*. According to C. W. Merriam, they are Eifelian (Middle Devonian) and represent coral zone F, which is equivalent to the Woodpecker Limestone Member of the Nevada Formation. These limestone bodies are, in part, patch reefs. The association of these fairly pure coral-bearing limestone lenses with carbonaceous shales implies unusual environmental conditions, as does some of the associated, rather coarse, sandstone, which contains abundant plant debris representing what appear to be terrestrial forms.

Helderberg fossils from northeast Washington

C. W. Merriam reports a fauna of Helderberg age from acid-etched material collected by F. K. Miller in Stevens County, northeastern Washington. This is the only known occurrence of Helderberg (Early Devonian) age in western North America except for the Rabbit Hill Limestone in the Great Basin. Other fossils in the Chewelah area, in northeastern Washington, appear to represent younger Devonian faunas.

Lower Paleozoic outlier in Colorado

A structure in Haystack Gulch quadrangle in Larimer County, Colorado, interpreted as a diatreme, has yielded corals that establish an Ordovician age for at least part of the carbonate rocks in this Paleozoic outlier within Precambrian terrain, according to Helen Duncan. One slab found by M. E. McCallum contains brachiopods that, though strongly altered and not identifiable as to genus, are almost certainly post-Ordovician forms. It seems likely that they may be Silurian, inasmuch as John Chronic and C. S. Ferris, Jr.,[43] reported the discovery of Ordovician and Silurian faunal assemblages at a comparable outlier near Tie Siding, Wyo., about 10 miles north of the Colorado locality. Both occurrences are remote from other areas of known lower Paleozoic rocks, and indicate that rocks of this age must have been much more widely distributed in this region than was formerly supposed.

Japanese fusulinids found in California

The Calaveras Formation in Amador County, Calif., has yielded several genera of fusulinid Foraminifera that are common in Japan but not previously reported from California, according to R. C. Douglass. Samples collected in September 1965 by Douglass and Prof. R. Morikawa, working together on a project sponsored by the United States–Japan Cooperative Science Program, contain fusulinid assemblages that suggest a direct Permian marine connection from California through western Washington and British Columbia to Japan.

Lower Pennsylvanian cephalopods from Nevada Test Site

A Lower Pennsylvanian cephalopod fauna has been collected from the basal part of the Tippipah Limestone in the Nevada Test Site in Nye County, Nev., by Mackenzie Gordon, Jr., together with F. C. Poole and other Survey geologists at the Test Site. Similar material has recently been found in the same strati-

[43] John Chronic and C. S. Ferris, Jr., 1961, Early Paleozoic outlier in southeastern Wyoming, *in* Symposium on lower and middle Paleozoic rocks of Colorado, 12th field conference: Denver, Colo., Rocky Mountain Assoc. of Geologists, p. 143–146.

graphic position near Indian Springs in Clark County, Nev. Studies by Gordon of this fauna show that it contains the ammonoid genera *Bisatoceras*, *Syngastrioceras*, *Branneroceras*, and *Stenopronorites* and is probably of late Morrow age. The occurrence of these fossils a few feet above conglomerate beds which occur locally at the base of the formation indicates the presence of an hiatus representing much of Early Pennsylvanian time.

Permian coleoid cephalopods from the Phosphoria Formation

Mackenzie Gordon, Jr. (p. B28–B35) reports that belemnitelike coleoid cephalopods of the family Aulococeratidae occur in two phosphatic shale members of the Phosphoria Formation. The Meade Peak Member of Early Permian age contains *Stenoconites idahoensis* at four localities in southeastern Idaho. This is the oldest Permian coleoid known. The Retort Member of Late Permian age contains "*Dictyoconites*" cf. "*D.*" *groenlandicus* Fischer at six localities in southwestern Montana. "*D.*" *groenlandicus* was originally described from northeastern Greenland. Both genera appear to be closely related to, but not identical with, true *Dictyoconites* of the Alpine Triassic. A fairly direct seaway connecting Greenland and southwestern Montana is implied by the distribution of "*Dictyoconites*."

MESOZOIC OF THE UNITED STATES

Biostratigraphic classification of the North American marine Triassic

During the past 2 years N. J. Silberling has collaborated with E. T. Tozer, of the Geological Survey of Canada, in a revision of the ammonite zonation and time-stratigraphic subdivision of the marine Triassic in North America. Joint field studies of the composition and stratigraphic succession of Triassic ammonite faunas were carried out in the conterminous Western United States during 1964 and in northeastern British Columbia during 1965. At present, 35 distinct ammonite zones, some of which incorporate still more refined local faunal units, are recognized in the Triassic of North America. About four-fifths of these zones are recognized in both the United States and Canada or provide an objective faunal basis for correlating strata from one region to the other.

Kayenta tritylodonts related to Late Triassic genera

Detailed morphologic analysis by G. E. Lewis has confirmed the relatively close relationship of the new American tritylodonts from the Kayenta Formation and the latest Triassic genera of the Old World. The closest Old World relative is *Tritylodon*, from the Stormberg Beds of South Africa. To a lesser degree, likeness to *Bienotherium*, from the Lufeng of China, can be demonstrated. Relationships with the earliest Jurassic *Oligokyphus* of Europe are remote, and the Middle Jurassic *Stereognathus* is even farther removed.

Jurassic gastropods of central and southern Utah

A study by N. F. Sohl (r1612) of gastropod faunas in the Carmel Formation and the Twelvemile Canyon Member of the Arapien Shale indicates that gastropods are more common in the central area of outcrop of the Carmel and lessen in diversity and abundance in the thinner, sandier, nearshore sediments to the east. The provincial nature of Jurassic gastropods is shown by the fact that, while the Gulf coast and Western Interior faunas are similar in some respects, there are no species in common. The greatest gastropod diversity occurs in the Middle Jurassic (Bathonian and Lower Callovian) of the Western Interior as compared to a Late Jurassic diversification in the Gulf coast and west Texas region.

Upper Cretaceous ammonite zones in Western Interior

W. A. Cobban has constructed an ammonite time scale for the latter half of the Late Cretaceous in the Western Interior region. The recognition of 38 ammonite zones, representing the Coniacian, Santonian, Campanian, and the lower half of the Maestrichtian Stage, results in a better correlation of strata and a more accurate reconstruction of geologic events in the Late Cretaceous for a large part of the United States.

Eagleford ostracode in Utah

The Upper Cretaceous ostracode species *Cythereis eaglefordensis* has been identified by J. E. Hazel from material collected by Fred Peterson in the Tropic Shale of southern Utah. This widespread species occurs also in the middle part of the Britton Clay of Adkins, and Eagle Ford Shale, in Texas, and in the lower part of the Atkinson Formation, in the subsurface of the Southeastern States. This species, which appears to be a microfossil indicator of the *Sciponoceras gracile* zone of the Western Interior or of its Gulf coast equivalents, will provide a tie with other rocks of this age where ammonites are absent.

Cretaceous discoveries in Puerto Rico

N. F. Sohl has made three major Upper Cretaceous discoveries in Puerto Rico: (1) Well-preserved ammonites, found in normally unfossiliferous beds near El Yunque, should provide a firm age assignment for these strata. (2) A diversified shallow-water molluscan assemblage collected from shales of the *Titanosarcolites* rudist assemblage in the Barranquitas quadrangle is the youngest Cretaceous nonrudist molluscan material so far reported from the island. (3) A rudist-coral bioherm in the San German quadrangle is directly overlain by beds with *Inoceramus* and ammonites. The stratigraphic ranges of several of the more common rudists can now be determined for the first time.

Late Cretaceous fossils from Blake Plateau

A large assemblage of Late Cretaceous marine invertebrates has been identified from two collections of pebbles dredged from the Blake Plateau, off the coast of South Carolina, during the cruise of the R/V *Gosnold* in September 1965. Cephalopods, pelecypods, gastropods, corals, Foraminifera, and fish teeth of probable later Campanian age were examined by W. A. Cobban, E. G. Kauffman, N. F. Sohl, J. W. Wells, J. F. Mello, and D. H. Dunkle. The fossils show a long history of reworking and redeposition. The shells contain borings which are filled with Tertiary Foraminifera; and the pebbles containing the fossils are covered with modern bryozoa and serpulid worm tubes.

Microfaunal zones in Cretaceous rocks of northern Alaska

H. R. Bergquist [48a] has recognized six microfaunal zones within the Cretaceous formations in northern Alaska. Beginning with the oldest these are: the *Gaudryine tailleuri* and *Verneuilinoides borealis* zones of Albian age, the *Gaudryina irensis–Trochammina rutherfordi* zone of Cenomianian age, the *Hedbergella loetterlei–Heterohelix globulosa* zone, and the *Pseudoclavulina hastata–Arenobulimina torula* zone of Turonian age, and the *Neobulimina canadensis* zone of Senonian age. Subzones occur in each zone except the lowermost. The zones, which can be traced in the subsurface throughout most of Naval Petroleum Reserve 4, have been extremely useful in regional correlations. This region is one of the first in North America where extensive correlations by the use of arenaceous Foraminifera have been possible over a large area.

[48a] H. R. Bergquist, 1966, Micropaleontology of the Mesozoic rocks of northern Alaska: U.S. Geol. Survey Prof. Paper 302–D, p. 93–227, 12 pls., 17 figs. [published July 1966]

MESOZOIC AND CENOZOIC NONMARINE FOSSILS OF THE UNITED STATES

Mesozoic and Tertiary palynological provinces

A study of pollen and spore assemblages in the vicinity of the Cretaceous-Tertiary boundary in the Rocky Mountain region and in the Mississippi embayment by R. H. Tschudy demonstrates that latest Cretaceous pollen assemblages from these regions differ to a remarkable degree. Clearly, two distinct floral provinces contributed pollen and spores to the respective sediments. The assemblage from the Mississippi Embayment region yielded many fossils generically similar to the *Normapollis* group of genera reported from the Upper Cretaceous of Europe. Conversely, the assemblage found in the Rocky Mountain region is almost devoid of representatives of the *Normapollis* group of genera.

Seeds from Morrison Formation

Hundreds of silicified seeds have been recovered from a locality discovered by Charles Bass in the Upper Jurassic Morrison Formation of Utah. Despite the presence of much organic trash in the Morrison, few recognizable plant fossils have previously been found in this formation. These seeds, being studied by M. E. J. Chandler, of the British Museum (Natural History), and R. A. Scott, represent a variety of plants, including some gymnospermous forms with reproductive structures unlike any previously described.

Eocene diatoms from Wyoming

A distinctive assemblage of fresh-water diatoms has been found in association with a gastropod fauna in limestone from the Wagon Bed Formation of Eocene age. Preliminary examination by K. E. Lohman and G. W. Andrews suggests that occurrence of at least one new genus and several new species of diatoms. With the exception of one questionable sample, this is the only occurrence of fresh-water diatoms known in rocks of pre-Miocene age in North America. Because the diatom assemblage from the Wagon Bed Formation contains several well-differentiated genera, these fresh-water diatoms apparently had a long early history which is not yet known. The absence of diatoms in many older Tertiary rocks can be attributed principally to lack of preservation of the fine-textured siliceous diatom frustules.

Eocene cashews from Wyoming

A fossil fruit, collected by Charles Bass from the Tepee Trail Formation (upper Eocene) of Wyoming, has been identified by R. A. Scott as the genus *Poupartia*, a member of the cashew family. This is the first record of this genus in North America. Modern species of *Poupartia* grow in Madagascar and the Mascarene Islands.

Pollen in Searles Lake sediments

Pollen diagrams for three cores of Searles Lake, Calif., sediments were prepared by E. B. Leopold. The cores penetrate as far as 130 feet and, according to C^{14} evidence, the sediments range in age from Recent to 40,000 years Before Present.

Modern pollen-rain samples from 11 trapping stations in an east-west transect across the playa were collected during 1964 for comparison with the fossil pollen. The modern pollens comprise 5 groups which correspond to the plants that now grow in the following areas: (1) locally on the playa margin, (2) on nearby arid mountain ranges, (3) in the Sierra Nevada, 35 to 300 miles west and northwest of the playa, (4) in the Great Valley and southern Coast Ranges, Calif., 80 to 120 miles west or south of Searles Lake (*Juglans*, *Fremontia*), and (5) in areas other than the Great Basin (*Carya*, now planted in California). No qualitative stratigraphic changes in pollen assemblages were found in the cores studied. The relative abundance of *Pinus*, *Juniperus*, and Compositae pollen fluctuates greatly throughout the cores, but in general the major patterns of oscillation do not correlate from core to core.

Pollen which is transported into the basin from great distances (35–120 miles) makes up the same fraction of the modern pollen rain at all stations, while pollen from local plants shows a differential distribution depending on the nature of local vegetation. A comparison of trapped pollen with that in local soils indicates that a marked differential destruction of fragile pollen types occurs in alkaline soils but not in normal ones.

Distribution of Pliocene and Pleistocene nonmarine mollusks

Research by D. W. Taylor indicates that about 50 to 55 late Pliocene to early Pleistocene nonmarine mollusk faunas are known in North America. These faunas show both provinciality and regional differences in the percentages of extinct groups and locally endemic forms. Because tectonic activity promoted taxonomic differentiation, the stratigraphic value of these mollusks is greater in tectonically active areas than in stable ones. The congruence of the modern faunal distribution and late Pliocene distributions shows that late Cenozoic events, not present-day drainage or habitats, determined the range of many living species.

Tertiary fresh-water mollusks, Powder River basin

Several successive assemblages of fresh-water mollusks can be recognized in the lower Tertiary rocks of the Powder River basin, in Wyoming and Montana, and correlated with those of other basins, according to D. W. Taylor. Faunal zonation of the widespread Fort Union Formation is now possible, and correlation between well-dated areas indicates that it is partly of earliest Eocene age. The refinement of local zonation in the Powder River basin permitted refinement of the correlation of coal beds and the mapping of formational boundaries. Progressive changes in the mollusk fauna are consistent with an earlier supposition that drainage was reversed from south to north in early Eocene time. Evidence of immigration between the Powder River and Green River basins offers a new possibility for refined correlation between these two areas.

Muskox from Big Bone Lick dated as Tazewell

Examination by F. C. Whitmore, Jr., of the type skull of *Bootherium bombifrons*, an extinct muskox collected by Captain William Clark in 1807 at Big Bone Lick, Ky., showed that after 158 years the braincase still contained silty matrix including plant fibers. With the permission of the Academy of Natural Sciences of Philadelphia, from which the specimen has been borrowed, the matrix was removed and samples were submitted by Meyer Rubin and E. B. Leopold for analysis. Rubin reports that the matrix is dated at 17,200±600 years Before Present (climax of the Tazewell Stade of the Wisconsin Glaciation). Leopold found a predominance of spruce pollen, indicating a climate colder than that of the present. The C^{14} date is the oldest so far obtained from Big Bone Lick material, and indicates the probable existence of a fauna older than those so far collected by Whitmore and the University of Nebraska field party with which he has been working.

CENOZOIC OF THE PACIFIC COAST REGION

Eocene reefs in Washington

Four genera of probable late Eocene larger Foraminifera have been identified by K. N. Sachs from a limestone lens interbedded in basaltic volcanic rocks in Jefferson County, Wash. The fossils were collected by W. M. Cady. These Foraminifera, of a kind which lived in relatively shallow, clear, warm marine waters, indicate an environment quite like that of modern-day reefs. This occurrence is the farthest north of any known in North America for Tertiary larger Foraminifera.

Miocene paleoenvironments in Kern River area

Miocene gastropods of the Kern River area, California, constitute the largest late Tertiary assemblage known from the Pacific coast region, according to W. O. Addicott. Many tropical genera previously unreported from as far north as California attest to the tropical aspects of the middle Miocene invertebrate faunas of this area. Because both the early and late Miocene faunas in this part of California are of a cooler-water aspect, the new find suggests a middle Miocene warm pause within the predominantly cooling trend of the Tertiary.

Paleoenvironment of Monterey Formation

P. J. Smith is studying the age and paleoenvironment of the Miocene Monterey Formation, in the Salinas Valley in California, on the basis of its foraminiferal faunas. In the northern part of the valley (Reliz Canyon area) the calcareous facies of the Monterey is lower Miocene (Saucesian Stage) to lower upper Miocene (Mohnian Stage), and it is overlain by a thick section of upper Miocene siliceous rocks. Phosphate occurs in the uppermost middle Miocene beds. Farther south, the calcareous facies is middle Miocene in age, and the faunas indicate a bathyal paleoenvironment. At the southern end of the valley (Indian Creek area) the entire Monterey Formation is middle Miocene (Relizian and Luisian Stages). The Relizian and lower Luisian rocks are calcareous, and bathyal depths are indicated; the upper Luisian rocks are siliceous and phosphate bearing, and the faunas indicate a shallow neritic environment.

Early Miocene mammals in Nevada

New collections of fossil mammals by C. A. Repenning and R. R. Coats, from the Rizzi Ranch local fauna in northern Elko County, Nev., indicate an early Miocene age. For many years the fauna was considered to be of middle to late Miocene age. The collections include forms typical of the John Day fauna of east-central Oregon. The more definitive fossils are the aplodontid rodent *Meniscomys hippodus* Cope and the primitive beaver *Capacikala gradatus* (Cope). Others include a primitive cricetid rodent similar to the genus *Paciculus*, a canid similar to Nothocyon, a merycoidodont, and a small rhinoceros questionably referred to the genus *Diceratherium*. Two other localities in the Rizzi Ranch area that have been assumed to be of the same age contain a late Miocene species of horse comparable to *Merychippus seversus*. Except for the isolated find near Indian Spring, White Pine County, of a single small rhinoceros premolar which may be from *Diceratherium*, of early or middle Miocene age, the Rizzi Ranch locality provides that first early Miocene mammals from Nevada.

Oligocene fluctuations in climate

Re-analysis by J. A. Wolfe of Oligocene floras in the Pacific Northwest, in the light of recent potassium-argon age determinations, indicates that a major climatic deterioration occurred about 30 million years ago. Floras of early Oligocene age are of subtropical to tropical character, but floras only 3 million years younger (middle Oligocene) are temperate, and even cooler than late Oligocene floras. Because of the rapid rate of this deterioration and of its apparently regional aspect, the change in the floras should provide a useful and precise tool for nonmarine stratigraphy in the northwestern United States.

Late Miocene cooling in Alaska

Neogene floras in Alaska show that the climate was temperate to warm-temperate during most of the Miocene, but a definite cooling to a cool-temperate climate occurred during the late Miocene. According to taxonomic and biostratigraphic studies by J. A. Wolfe, this cooling trend apparently occurred over a short period of time and effectively partitioned the coniferous forests of North America and Asia.

Palearctic-Nearctic mammalian dispersal during the later Cenozoic

In a review of the later Pliocene and Pleistocene mammal faunas of temperate Eurasia and North America, C. A. Repenning (r0207) has found that at least three intercontinental faunal exchanges took place during this time. There was progressive increase in the ability of Eurasian forms to enter North America. Thus, the proportion of Old World taxa migrating to America, relative to New World taxa migrating to Eurasia, changed as follows: about 2/1 in the middle Pliocene (Hemphillian mammal age), 3/1 in the late Pliocene and early Pleistocene (Blancan mammal age), 5/1 in the middle Pleistocene (Irvingtonian mammal age), and 18/1 in the late Pleistocene (Rancholabrean mammal age). This difference in dispersal direction appears to be related to the nature of glaciation in North America and Siberia. Boreal forms evidently could not evolve in North America when extensive ice sheets virtually eliminated this environment, but spotty glaciation in Siberia permitted Arctic faunas to develop, which could disperse into northern America with the withdrawal of continental ice there. This increasing bias toward Asian immigrants to North America leads to increasing uncertainty of correlation between the two continents. Time lag in dispersal cannot be evaluated in many instances without the benefit of two-way intercontinental migrations of time-significant mammals. Hence it seems reasonably certain from the evidence of fossil mammals that the arbitrary base of the European Pleistocene (base of the Villafranchian Stage) is to be equated with some time within the North American Blancan age. However, it is progressively less certain that the Blancan-Irvingtonian and Irvingtonian-Rancholabrean faunal boundaries coincide with faunal boundaries in Europe customarily considered to represent the early-middle and middle-late Pleistocene time boundaries.

OTHER PALEONTOLOGICAL STUDIES

Tertiary Foraminifera from the island of Midway

Ruth Todd and Doris Low have found a zone of abundant *Austrotrillina* at 1,116 feet in core from the deep hole drilled on the island of Midway. This miliolid genus is known only from the Oligocene and Miocene, and only in the Tethyan region—from Spain through the Middle East to Australia—and in the central Pacific (Bikini and Eniwetok). The Midway occurrence extends its geographic range eastward, and the species appears to confirm a Tertiary *e* age in the Midway hole. Tentative correlations between the Midway sequence and that in the Marshall Islands were made at two levels in the Miocene. It is probable that several zones in the Marshalls can be extended to Midway, and that a useful sequence of foraminiferal faunas in the late Tertiary reef facies of the Pacific region can be documented.

Relative abundance of planktonic Foraminifera and Radiolaria

Along a north-south plankton traverse in the western North Atlantic and Caribbean, Richard Cifelli, of the U.S. National Museum, and K. N. Sachs found Foraminifera to be more abundant than Radiolaria in the north; Radiolaria were the more abundant in the south. With one exception, however, numbers of specimens of the two groups were within an order of magnitude of each other, and changes in abundance of the two groups showed a striking parallelism. These findings suggest favorable coexistence, and are in contrast to the distribution of Foraminifera and Radiolaria in surface sediments of the bottom of much of the southern North Atlantic (where Foraminifera far outnumber Radiolaria). They also contrast to conditions in the Pacific, where Radiolaria have been reported to be generally common in bottom sediments.

Foraminiferal parasite on bivalve

An unusual occurrence in deep water (951 meters) in the Gulf of Guinea, off the west coast of Africa, appears to be the first reported instance of penetration of a living clam by a foraminifer, according to Ruth Todd (r0552). Large specimens (up to 6 mm in diameter) of a new species of the foraminifer *Rosalina* were found attached to the umbonal regions of the bivalve *Lima.* Numerous attachment scars on the exterior, and penetration scars—some entirely and some partially healed—on the interior of the bivalve, were present. The penetration is attributed to search for calcium carbonate, by the foraminifer, for use in shell building.

Foraminifera from Arctic Ocean off eastern Siberian coast

Ruth Todd and Doris Low (p. C79–C85), studying bottom samples collected by the USCG cutter *Northwind* from the shallow continental shelf off the Arctic coast of eastern Siberia, found a composite fauna of 56 species of Foraminifera. The fauna is impoverished, and aberrant specimens occur in unexpectedly high numbers, probably because of unfavorable habitats produced by low salinity and great seasonal variations in water conditions. No planktonic Foraminifera were found.

American ostracode found in Hawaii

The ostracode *Cyprideis* has been reported by J. E. Hazel, for the first time in Hawaii, in samples from a 1,000-foot well on the Ewa plain. Although this genus can tolerate normal marine salinities, its maximum development is under mesohaline conditions. It now lives along the coasts of southern California, Mexico, and Chile, and is found fossil in the Pleistocene of California. It could not have migrated to Hawaii (or from Hawaii to the Americas) across the eastern Pacific. The ostracode is thought to have been carried by migratory birds. Hawaii is not now on the flyways of the requisite migratory shore birds, but the ostracode may have been introduced into Hawaii by an accidental migrant or, possibly, if during the Pleistocene, by birds whose flyways differed from those of the present because of glaciation in breeding areas.

Muscle scars useful in ostracode taxonomy

Studies by J. E. Hazel [49] indicate that the muscle scars found on the valves of living and fossil ostracodes are much more useful taxonomically than had been realized heretofore. Not only do they aid in

[49] J. E. Hazel, in press, Classification and distribution of the Recent Hemicytheridae and Trachyleberididae (Ostracoda) off northeastern North America: U.S. Geol. Survey Prof. Paper 564.

delineating groups in the difficult families Hemicytheridae and Trachyleberididae, but also scar patterns can be demonstrated to change through time, and a reasonable phylogenetic history of the two families can be suggested. The complex muscle-scar patterns found in most modern genera of hemicytherids developed from those of the trachyliberids in a series of steps beginning in latest Cretaceous time and continuing through the Tertiary to the present day.

MARINE GEOLOGY AND HYDROLOGY

The U.S. Geological Survey is continuing its diversified investigations of the geology and hydrology of the marine environment, including studies in bays and estuaries along coasts and on scattered oceanic islands and reefs. The regional reconnaissance of the Atlantic continental margin was again the principal marine investigation of the Geological Survey during the 1966 fiscal year; also, marine studies related to earthquakes were continued on the west coast. In addition, investigation of the beaches, coastal terraces, and related offshore deposits of the west coast, including Alaska, was started near the end of the fiscal year. The investigation is a part of the Survey's search for heavy metals (p. A4). It will be carried out in part by collaborative contracts with institutions and universities.

ATLANTIC CONTINENTAL MARGIN

During 1965, the reconnaissance studies of the Atlantic continental margin shifted in emphasis from surficial sampling of the continental shelf and slope to the collection of information concerning the composition and structure of the underlying rocks. The studies, which are being carried out jointly by the U.S. Geological Survey, the Woods Hole Oceanographic Institution, the U.S. Bureau of Commercial Fisheries, and other organizations, are directed by K. O. Emery of the Institution. Information on the nature of subsurface rocks has been obtained through cooperation in an offshore drilling project, the dredging of submarine slopes, and seismic subbottom structural profiling.

Offshore drilling

The highlight of marine activities off the Atlantic coast during 1966 was the drilling of six core holes on the continental shelf and on Blake Plateau, off northern Florida. The U.S. Geological Survey cooperated in the drilling, which was sponsored by JOIDES (Joint Oceanographic Institutions Deep Earth Sampling) and supported by the National Science Foundation. J. S. Schlee, of the Geological Survey group at Woods Hole, Mass., served as principal scientist and directed the collection and description of the cores; other members of the Geological Survey also participated.

The holes were drilled in water ranging in depth from 30 to 1,032 meters; the deepest hole extended 320 m below the sea floor. Rocks as old as Paleocene were penetrated. Eocene and Miocene formations of Florida and Georgia continue seaward beneath the continental shelf. Lithologic studies of the cores and logs by J. S. Schlee, R. L. Wait, Eugene Shuter, and G. W. Leve suggest gradual accumulation of sediments on the continental margin east of Florida and Georgia. Phosphatic zones were identified in the cores and on gamma-ray logs that were obtained by Eugene Shuter and R. L. Wait. The lithologies found in cores and indicated by gamma-ray logs show that terrigenous materials such as quartz, feldspar, and rock fragments are common sand-size constituents only in samples from the holes on the shelf, according to D. A. Ross, of the Institution. The amounts decrease with depth, suggesting a smaller supply of land-derived material, greater biologic productivity, or both, in pre-Miocene time. Significant amounts of heavy minerals were found in 11 of 52 samples from the nearshore holes. The relatively unstable epidote-amphibole-staurolite assemblage indicates derivation from an igneous and metamorphic source terrane. According to J. C. Hathaway, of the Geological Survey, and P. F. MacFarlin, of the Institution, calcite is the dominant mineral of most cores. Clay minerals, including montmorillonite, palygorskite, and sepiolite, are abundant in many Miocene specimens; moderate amounts of clay are present in a few Oligocene and Eocene samples.

Studies by F. T. Manheim of the soluble components of the cores indicate concentrations of rare earths and uranium. His chemical studies of the interstitial waters suggest that some of the water may have a Pleistocene age but that most of it appears to be nearly equivalent in age to that in aquifers on land that extend seaward beneath the continental shelf. In general the chlorinity of the interstitial waters increases with depth in the holes to a maximum of 27 ‰. Several prominent reversals in the trend, reflecting the presence of aquifers, are present at the edge of the continental shelf, 80 kilometers from shore. A hole about 35 km east of Jacksonville, Fla., passed through upper and middle Eocene rocks that contain fresh water similar to that beneath coastal Georgia and Florida. G. W. Leve and R. L. Wait measured an artesian head of about 12 m above sea level.

Manganese pavement and phosphatic nodules dredged on Blake Plateau

Through dredging on the Blake Plateau, R. M. Pratt and P. F. MacFarlin, of the Woods Hole Oceanographic Institution, were able to delineate a manganese pavement that may be unbroken throughout an area of 5,000 square kilometers. The pavement is bounded by areas of manganese and phosphate nodules. The phosphate nodules from two localities contain fossils of Late Cretaceous age.

Seismic profiling yields new subbottom information

About 8,000 kilometers of continuous seismic (sparker) profiles were made along and across the continental shelf between Nantucket Island, off the coast of Massachusetts, and Miami, Fla., supplementing the 8,000 km of profiling during 1963 and 1964 in the Gulf of Maine and on the adjacent continental shelf and slope. On the basis of this work Elazar Uchupi and K. O. Emery, of the Woods Hole Oceanographic Institution, have shown that the continental margin was formed by upbuilding on the shelf and by seaward progradation on the continental slope. In some areas this primary structure has been modified by submarine erosion of the slope. The only areas where evidence of faulting has been observed are south of the Florida Keys and east of Miami.

A. R. Tagg, of the U.S. Geological Survey, and Uchupi, of the Institution, (p. B95–B98) showed that Triassic rocks extend beyond the mouth of the Bay of Fundy in a long northeast-southwest-trending basin for a distance of about 120 km. The rocks appear to have been deeply eroded by glacial action during Pleistocene time. After retreat of the ice, and accompanying a rise in sea level, the basin was partly filled with largely reworked sediments.

Using high resolution "boomer" continuous seismic profiling, D. W. Moody and others discovered a large buried channel of the Delaware River at the entrance to Delaware Bay. The channel lies 3 km northeast of Cape Henlopen, Del., at a depth of 56 meters below mean sea level. Many smaller buried channels occur beneath shoals southwest of Cape May, N.J., at depths of 6 to 52 m.

Ecology of offshore lancelet populations

Amphioxus, a small fishlike benthic animal usually about 2½ inches in length, is of interest as a possible food source. It is found in estuarine waters as well as on the continental shelf. According to studies by R. L. Cory and E. L. Pierce, an apparent belt of "lancelet sands" follows roughly the 20-meter depth contour for 250 miles between Charleston, S.C., and Cape Kennedy, Fla. Scattered, generally isolated specimens were collected as far north as Cape Hatteras, N.C., and along the South Carolina and Georgia coasts, where they numbered more than 10 per liter of sand or about 200 per square meter. They were absent from the fine, silty, nearshore sands, and sparse in the sediments beyond the 20-meter contour. Their distribution north of Cape Hatteras is probably limited by low winter temperatures (less than 9°C), and they are probably limited to the south by a change from siliceous to calcareous sand.

PACIFIC AND ALASKAN CONTINENTAL MARGINS

Geophysical observations at continental end of Aleutian arc

D. F. Barnes, of the U.S. Geological Survey, and W. H. Lucas and R. J. Mallory, of the Environmental Sciences Services Administration, have studied geophysical data from part of the continental shelf off Alaska. By combining marine and shoreline gravity data they have prepared contour maps that show anomalies associated with the continental end of the Aleutian arc. These anomalies are not as large as those associated with the oceanic portion of the arc, but they extend for long distances parallel to the arcuate geologic trends. Interpretation of the offshore anomalies by comparison with similar anomalies over known geology on land indicates that the upper Cenozoic sedimentary rocks of the Yakataga geosyncline extend from Middleton Island to the south end of Kodiak, but that the same rocks of the Cook Inlet geosyncline do not extend south of Homer. Another small basin of late Cenozoic age lies southwest of Kodiak and northwest of Tugidak.

Redondo submarine-canyon profiles

Multiple crossings of the Redondo submarine canyon, just west of the Los Angeles basin, were made with a sonic (sparker) profiler under the direction of G. A. Rusnak. Correlation of the five profiles by R. F. Yerkes demonstrates that west of long 118°25′ W., where the canyon is crossed by the northwest-trending Palos Verdes Hills fault, the canyon follows a S. 70° W. trending fault that juxtaposes shale of the Miocene Monterey Formation on the south and undeformed younger (Pliocene?) strata on the north. Vertical separation across the fault is about 1,300 feet. At its east end, near long 118°25′ W., the fault merges with the Palos Verdes Hills fault, and together these faults form the northern margin of the relatively high Palos Verdes Hills structural block.

MARINE GEOLOGIC ENVIRONMENT AND PROCESSES

Organic geochemistry of North Pacific deep-sea samples

From analysis of the organic matter of samples collected in cooperation with the U.S. Coast and Geodetic Survey, J. G. Palacas, V. E. Swanson, and G. W. Moore (p. C102–C107) concluded that two of the samples—one collected 150 miles north of Hawaii and one collected midway between Hawaii and the Aleutians—had less than 10 percent combined humic acids, bitumens, and amino acids. In contrast, a sample from the Aleutian Trench had 62 percent total organic matter, of which 59 percent represented the humic-acid fraction.

Clay-mineral analysis of red muds of North Pacific

Dorothy Carroll suggests, on the basis of preliminary study, that the principal clay mineral in the North Pacific marine red muds may be chamosite, and not kaolinite as is generally reported. The mineral of the red muds is authigenic and is coated with iron oxides. On heating, the principal X-ray reflection at about 7 A persists until nearly 600°C. The original iron-oxide coating changes to Fe_2O_3 on being heated at 900°C for several hours.

Iron-rich sediments from hot brine zones in Red Sea

J. C. Hathaway and F. T. Manheim, of the U.S. Geological Survey, and P. F. McFarlin, of the Woods Hole Oceanographic Institution, have determined more than 56 percent Fe_2O_3 and 6 percent ZnO in a core sample collected from a depression in the Red Sea. Iron is present as hydrous oxides amorphous to X-rays, and sulfides as very fine grains of sphalerite, pyrite, and heavy metals such as Cu (0.6 percent), Pb (0.1 percent), and Cd (0.04 percent). The geologic setting and the chemical and mineralogical nature of the sediments point to interaction between normal Red Sea water and hot brines emerging from underlying strata as the probable origin of the deposits.

Sepiolite and clinoptilolite from Mid-Atlantic Ridge

J. C. Hathaway (r1532) identified sepiolite in samples dredged from the Mid-Atlantic Ridge. The mineral is intimately associated with laminated clay and coccolith ooze, both of which contain clinoptilolite. The sepiolite seems to have formed by the reaction of magnesia, in solution with silica liberated during alteration of silicic volcanic ash.

ESTUARINE HYDROLOGY

Hydrogeologic investigation of tide-channel migration, Alaska

A study by S. H. Jones and A. J. Feulner in the upper Knik Arm estuary near Anchorage, Alaska, indicates that migration of the main tidal channel into lowland areas adjacent to the Alaska Railroad now amounts to 160 feet per year. The migration is attributed to strong reciprocative tidal-current action, and to the annual release of glacially formed Lake George into the Knik River. Downstream velocities during draining of the lake may reach 12 feet per second. The effects of local subsidence due to the earthquake of March 27, 1964, and to changes in the sediment discharge of the Eklutna River above the erosion area, caused by man's activities, are not well defined by available data.

Seismic-refraction surveys indicate that local bedrock exposures do not provide natural barriers adequate to protect exposed shorelines from erosion. The exposed bedrock, however, could be used as footings for protective structures undertaken to prevent further shoreline erosion.

Quality of water in Grays Harbor, Wash.

A study of bottom materials in the Grays Harbor estuary by J. P. Beverage and M. N. Swecker showed that a region of consistently high carbon content coincides with a sag in the longitudinal profile of dissolved oxygen. The observed carbon values were about 2 percent by weight, indicating a rather high potential dissolved-oxygen demand.

Influence of industrial and municipal wastes on water quality in estuaries

Increases in the concentration of ammonia and phosphate were observed by E. B. Welch in the Duwamish estuary at Seattle, Wash., following the introduction of effluent from a new activated-sludge sewage-treatment plant in June 1965. A phytoplankton bloom which occurred during the late summer of 1965 lagged behind the nutrient increase by about a month. However, nutrient levels in the Duwamish estuary during all 3 years it was studied were greater than those recorded in some other estuaries where more extensive blooms have been observed. Nutrient concentration is therefore thought not to be solely responsible for initiation of the bloom. The peak phytoplankton activity occurred during 1963 and 1965, years of low fresh-water discharge, when tidal-exchange volume and river discharge were at their minimums. In contrast, no pronounced peak in activity was observed in 1964, when the river discharge was much greater than during the other 2 years. These observations suggest that the retention time of water in the estuary may be a more important factor in promoting blooms than nutrient concentrations alone.

Phytoplankton production was found to increase dissolved oxygen in the surface layer of water during the late summer, when the most critical oxygen conditions are usually observed. However, algal cells that sink into the bottom water layers may contribute to an oxygen demand and cause lower concentrations of dissolved oxygen at depth.

SEA-WATER CHEMISTRY

Solubility of apatite in sea water

Experiments by C. E. Roberson (p. D178–D185) using fluorapatite and marine phosphorite in an artificial sea-water solution confirmed that the solubility of these substances in the solid phase is a function of pH. The data suggest that at pH 8.2 the equilibrium value for total dissolved phosphate is about 0.2 micromoles per liter. It is difficult to extrapolate the results of such experiments to the ocean environment, but it may be inferred that most ocean water (which has 1–3 micromoles of phosphate per liter, and pH near 8) is near saturation with respect to fluorapatite. Thus, the deposition of phosphorite, whose main component is fluorapatite, can be explained on continental shelves where a decrease in solubility occurs because of the loss of carbon dioxide. Results of studies with a saturometer, to determine whether sea water is saturated with respect to apatite or to phosphorite, were inconclusive, partly because of the overpowering influence of carbon dioxide as a pH buffering system.

ASTROGEOLOGY

The U.S. Geological Survey investigations in support of the space-exploration program of the National Aeronautic and Space Administration include: (1) earth-based lunar investigations, (2) studies of terrestrial and experimental impact and cratering phenomena, (3) cosmochemistry and petrology, (4) studies of images made from spacecraft, and (5) manned lunar-exploration studies.

EARTH-BASED LUNAR INVESTIGATIONS

Lunar geologic mapping

Lunar investigations are based on geologic mapping of the Moon at a scale of 1:1,000,000. The lunar equatorial belt, 70° W.–70° E. and 32° N–32° S., has been completely mapped in preliminary form. Geologic maps of the Aristarchus, Kepler, Letronne, Montes Apenninus, Riphaeus Mountains (Montes Riphaeus), and Timocharis quadrangles have been published in color (fig. 6), and colored maps of the Hevelius, Pitatus, Mare Humorum, and Mare Serenitatis quadrangles are in press or in final preparation. Preliminary uncolored maps of the Hevelius, Copernicus, Mare Vaporum, Grimaldi, and Theophilus quadrangles were previously completed. During 1965 the following preliminary uncolored maps were completed: Seleucus, by H. J. Moore; Mare Serenitatis, by M. H. Carr; Macrobius, by H. A. Pohn; Cleomedes, by A. B. Binder; Julius Caesar, by E. C. Morris and D. E. Wilhelms; Taruntius, by D. E. Wilhelms; Mare Undarum, by Harold Masursky; Ptolemaeus, by Harold Masursky; Colombo, by D. P. Elston; Langrenus, by J. D. Ryan and D. E. Wilhelms; Byrgius, by N. J. Trask; Purbach, by H. E. Holt; Rupes Altai, by L. C. Rowan; Fracastorius, by D. P. Elston; and Petavius, by D. E. Wilhelms.

Stratigraphic relations of ejecta from Mare Oriental and Mare Humorum

A preliminary map of the Byrgius quadrangle by N. J. Trask suggests that ejecta from both the Mare Orientale and the Mare Humorum basins are present. Much of the area between the two basins is composed of highly pitted material and patches of material that fills level uplands. The pitted terrain may represent fields of secondary impact craters formed by material ejected from the Mare Orientale and Mare Humorum basins. Lineaments are widespread in the quadrangle; most are oriented northwest-southeast.

Stratigraphy of Mare Serenitatis region

H. A. Pohn has mapped a low-lying area marginal to the northeast edge of the Serenitatis basin in the Macrobius quadrangle and named it the Serenitatis bench. The most widespread deposit on the bench is the Bond Formation, a new unit, which is flat overall but heavily cratered and dissected by rilles. It postdates the formation of the Serenitatis basin and predates the deposition of the mare material of the Procellarum Group. The Bond Formation appears to be an early generation of mare material. The Serenitatis bench and the Bond Formation of the Serenitatis basin are analogous to the Apennine bench and the Apennine Bench Formation of the Imbrium basin.

Facies of Fra Mauro Formation

The previously recognized hummocky and smooth facies of the Fra Mauro Formation, a widespread and well-defined map unit surrounding the Imbrium basin, have been mapped in the Mare Vaporum quadrangle

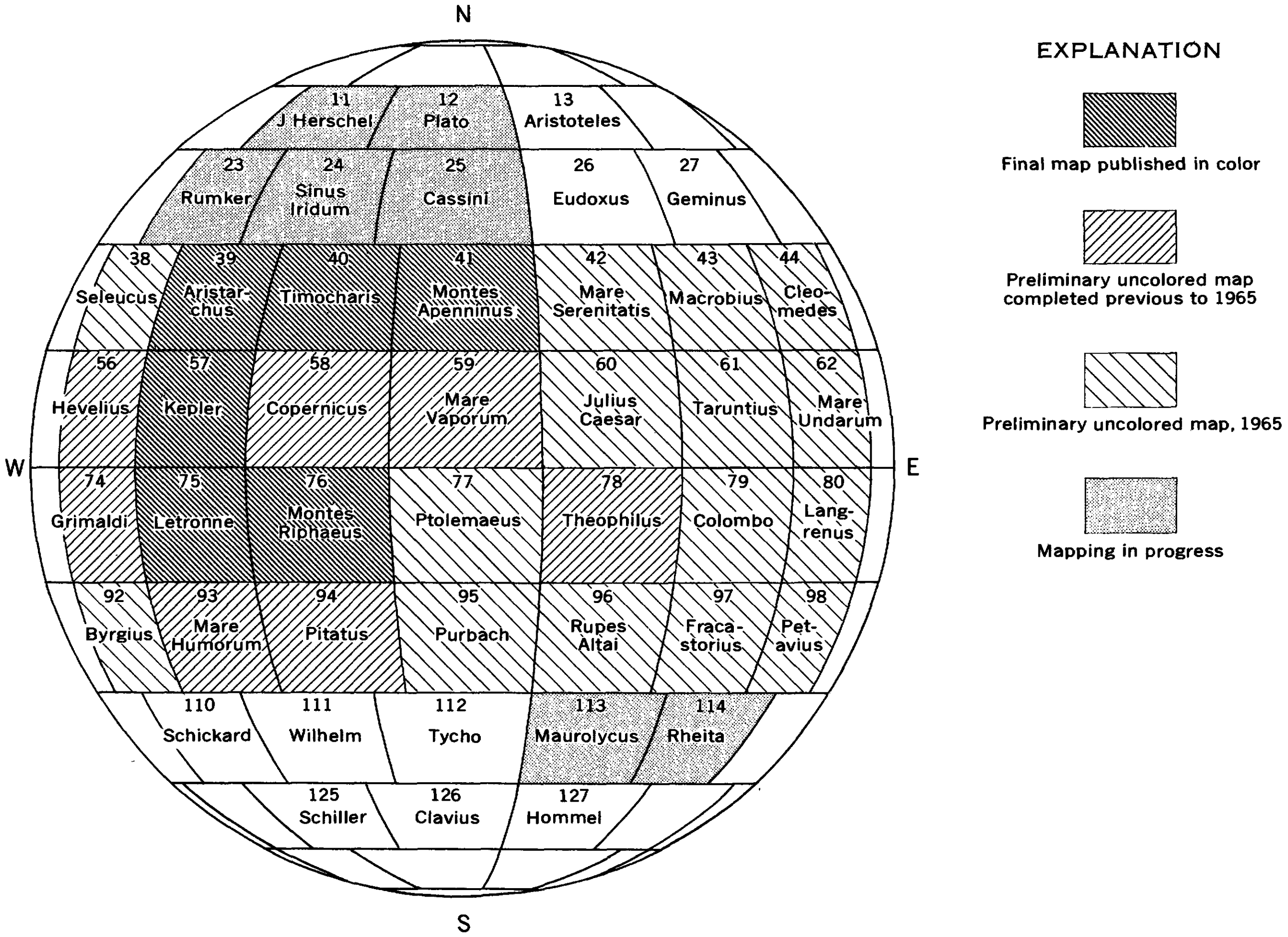

FIGURE 6.—Index map of the Moon, showing status of geologic mapping at a scale of 1:1,000,000. ACIC number and name are given in each region. Quadrangles shown with numbers but without patterns will be prepared in preliminary form in the 1967 fiscal year.

by D. E. Wilhelms and in the Julius Caesar quadrangle by E. C. Morris and D. E. Wilhelms. Wilhelms recognizes a pitted facies of the formation, and proposes a restricted definition of the smooth facies. Some material previously considered part of the smooth facies is withdrawn from the Fra Mauro Formation and assigned to a new unit, the Cayley Formation, in an attempt to clarify the relations and genesis of the materials in the vicinity of the Mare Imbrium basin. The sequence of the Fra Mauro facies from the northwest to the southeast is similar to the sequence of facies of crater rim materials from the rim crest radially outward from craters. Previous interpretations of both the Fra Mauro and the crater rim material as impact ejecta are supported by this study. The Cayley Formation is interpreted as mare-like material older than the Procellarum Group.

Volcanic deposits of Mare Serenitatis basin

M. H. Carr has mapped several probable volcanic units in the north-central part of the Moon. Most of these units are associated with rilles, and all have very low albedos. Within Mare Serenitatis, around the Littrow and Menelaus rilles, are dark units that terminate abruptly against the uplands and have scarplike contacts with the Procellarum Group. These two units are thought to be composed of volcanic flows that are younger than the rest of the mare material. Near the Sulpicius Gallus rille, and in an area 150 kilometers southeast of the crater Copernicus, dark materials with no intrinsic relief overlie both the Fra Mauro Formation and the Procellarum Group. These dark materials, interpreted as pyroclastic volcanic material, are also younger than the mare material. Other probable pyroclastic deposits occur around Sinus Aestuum amd Mare Vaporum, but these are older than the local mare surface.

Marius Hills volcanic complex

The Marius Hills volcanic complex, a broad, smooth plateau with many closely spaced domes in the western part of the Oceanus Procellarum, has been studied by J. F. McCauley. The complex embraces about 35,000 square kilometers. The domes are from 3 to 10 km wide and rise to heights of several hundred meters above the surface of the plateau. Two types of domes have been recognized: broad, low domes of the type common in the lunar maria; and less abundant, steep-sided domes with rille-like structures on their flanks. Many of the domes have small summit pits. The Marius Hills complex has a markedly lower density of craters than an area of comparable size directly to the east in Oceanus Procellarum, which it appears to postdate. It is in turn overlain by faint rays from the Copernican craters Kepler and Aristarchus and has, therefore, been given a tentative Eratosthenian age designation. The complex may represent a succession of post-Imbrian volcanic material. If this interpretation is valid, the two types of domes may have been formed by magmas of different composition.

Structural evaluation of large lunar basins

Completion of preliminary geologic mapping of the eastern part of the lunar equatorial belt by D. E. Wilhelms, Harold Masursky, A. B. Binder, and J. D. Ryan makes possible revised interpretations of the structural evolution of large craters and mare basins. Both Mare Crisium, a small mare basin with relatively few craters on its rim, and Petavius, the largest virtually unmodified crater of the lunar equatorial belt, have steep-sided depressions on the outer periphery of their rims. The walls of these depressions are parallel to the directions of the lunar grid. (The lunar grid is a system of lineaments on the surface of the Moon. The lineaments display four dominant trends.) Subsidence of the concentric trough around Mare Crisium probably occurred along these grid faults. Cross faults cutting the concentric troughs and ridges around most other mare basins also follow lunar grid directions rather than directions radial to the basins. A broad graben along much of the rim crest of Petavius may be a scaled-down representative of the shelves on the inner margins of several mare basins such as Imbrium, Humorum and Crisium. The shelves resemble this graben more closely than they do the terraces formed by inward slumping in smaller craters. The area also includes Langrenus, the largest known Copernican crater, upon whose rim flank is the largest known dark-halo crater. This dark-halo crater and other dark parts of the rim material may be the products of volcanic activity concentrated along lunar grid faults activated by the Langrenus impact.

Geology of lunar equatorial belt

The geology of the lunar equatorial belt (70° W.–70° E., 32° N.–32° S.) has been compiled at a scale of 1:5,000,000 by D. E. Wilhelms and N. J. Trask from the maps at the scale of 1:1,000,000. The history of a mare basin can be worked out in terms of the stratigraphic units in and around it; units older than, contemporaneous with, and younger than the basin are shown on the map. The units recognized as older than the basins are crater materials and undifferentiated regional materials; units which may be contemporaneous with the basins are chiefly the basin-rim materials; younger units are crater materials and regional plains-forming materials of the terrae and maria. The map also shows local units of possible volcanic origin, not related to basin history. The tentative order of formation of basins from youngest to oldest, is: Orientale, Imbrium, Crisium, Humorum, Nectaris, Serenitatis, Fecunditatis.

Discrimination of geologic units by use of polarization

D. E. Wilhelms and N. J. Trask have studied, by telescopic measurements with a Lyot polarimeter, the polarization properties of 20 regions on the lunar surface involving 10 currently recognized geologic units. They find that the value of maximum polarization differs considerably among these units and can aid in their discrimination. For units with widely differing albedos, maximum polarization and albedo are inversely related. Among some mare units with a relatively small spread in albedo, the polarization of some of the darker units appears to be anomalously lower than that of some of the brighter units.

Albedo map of lunar equatorial belt

L. C. Rowan and M. N. West have prepared a map showing the albedo variations in the region of the lunar equatorial belt from 20° N. to 20° S. and from 60° W. to 60° E. Units of albedo corresponding to density on a full-moon photographic plate were established by a photographic technique. Film negatives, each showing a progressively higher albedo unit, were projected upon an enlarged photograph of the same full-moon plate, and areas of equal albedo were outlined. The resulting information was adjusted to an orthographic-projection chart (scale, 1:5,000,000), and has been used in the preparation of some of the 1:1,000,000 lunar geologic maps.

Laser-radar selenodesy

Robert Wildey has studied and affirmed the feasibility of using laser ranging techniques to measure the shape of the Moon. Laser technology does not permit bursts larger than 10 joules at 1-second intervals; measuring times of 5 to 10 minutes per range point, or longer when measurements are made very near the limb, are necessary to obtain 50- to 100-meter accuracy in the reduced radius vector. Uncertainties in the Moon's range and vibration and libration ephemeris are small enough to permit nominal spherical curvature to be used in the metric tensor describing the wandering of the range point over the lunar surface away from a preselected target. The effect can therefore be corrected in deriving the lunar figure.

Roughness of lunar surface as related to infrared observations

Previous explanations by Pettit and Nicholson of their 1930 infrared observations imply significantly steeper slopes at a scale of 1 kilometer than exist on the Moon. Kenneth Watson (U.S. Geol. Survey, r1929, p. A132) suggested that one possible explanation of both the full-moon and subsolar infrared observations is the existence of surface roughness on a scale between 1 centimeter and 1 meter. During this past year he constructed theoretical sloped models of the surface and computed the infrared emission assuming that the individual surface elements are Lambertian. A reasonable fit to Pettit and Nicholson's full-moon observation was obtained for a mean slope of 18°. Extrapolation of terrestrial observations and of Ranger studies of lunar surface roughness versus scale suggests that the computed mean slope corresponds to a slope length between 1 and 10 cm. Future broadband infrared emission studies from the Manned Lunar Orbiter will provide useful textural detail two orders of magnitude better than photographs in visible wavelengths.

Photographic photometry

Photographic photometry, although inherently subject to errors much larger than those in photoelectric photometry, can in no case be carried out without some kind of calibration of the dependence of photographic density on exposure (brightness at exposure time). Many older plates are photometrically valueless because of the lack of such calibration. H. A. Pohn and R. L. Wildey have investigated methods of using these older plates. By taking density readings of selected spots on an old plate, and also making photoelectric measurements through the telescope of these same spots when the moon nearly duplicates the phase and libration corresponding to the epoch of the old plate, the calibration can be regained. It is assumed that there are no secular effects in the Moon's reflectivity and that lack of knowledge of the spectral sensitivity of the old plate is not an important factor. In addition, by using many lunar spots, one can measure, and can even provide limited compensation for, photometric nonuniformity of the original plate.

Terrain analysis

Lunar terrain-analysis studies have been made by L. C. Rowan and J. F. McCauley. Detailed analysis of the lunar surface, for either scientific or engineering purposes, requires abundant reliable topographic data which heretofore have been lacking. This additional information is required to support both the current lunar geologic investigations and the engineering studies directed primarily toward the problem of selection of a lunar landing site. The area of principal concern is that bounded by ±10° latitude and ±60° longitude. The objectives of the program are to:

1. Develop simple, readily usable statistical parameters applicable throughout the range of observable lunar-terrain types.
2. Improve earth-based photometric slope-measuring techniques in order to supplement the existing, relatively meager supply of lunar-slope data.
3. Classify the lunar surface statistically, within the area of the equatorial belt, into terrain units of varying degrees of measurable roughness.
4. Prepare a terrain map, at a scale of 1:1,000,000, showing the distribution of these units.
5. Use the statistical data and the terrain map, where possible, to improve definition of the rock- and time-stratigraphic units currently recognized within the equatorial belt.

STUDIES OF TERRESTRIAL AND EXPERIMENTAL IMPACT AND CRATERING PHENOMENA

Sierra Madera structure, Texas

Detailed mapping of Sierra Madera, a nearly circular structure of possible impact origin in western Texas, was extended by H. G. Wilshire to the ridge north of that mapped earlier by Shoemaker and Eggleton.[50] All the formations mapped, from the Permian Gilliam Limestone to the Cretaceous Edwards Limestone, are severely deformed. The principal structures mapped are steep normal(?) and reverse faults that trend nearly at right angles to the transverse faults mapped by Shoemaker and Eggleton, and thrust faults that resulted in movement of Permian rocks away from the center of the structure and over the Cretaceous.

Meteorite craters at Henbury, Australia

D. J. Milton has extended his study of the meteorite craters at Henbury, Australia to the great variety of structures in the walls and rims of the three larger

[50] E. M. Shoemaker and R. E. Eggleton, 1964, Re-examination of the stratigraphy and structure of Sierra Madera, Texas, *in* Astrogeologic studies, annual progress report, August 25, 1962, to July 1, 1963: U.S. Geol. Survey open-file report, p. 98–106.

craters. Beds originally dipping into the main crater were deformed into concentric folds overturned outward, most of which have steeply dipping axial planes. On the opposite wall of the main crater, beds which originally dipped away were deformed into a series of folds with gently dipping axial planes; an overturned flap on the outer rim of the crater in part is thrust outward as well as overturned. Elsewhere some thrust faulting also accompanied the folding. There is, in general, structural continuity between the crater walls and rims. Outside the rim crests, the ejected materials become progressively more broken, but there is rarely a clear line between coherently deformed rock and throwout debris.

Flynn Creek structure, Tennessee

D. J. Roddy is completing detailed geologic mapping of the Flynn Creek structure at scales of 1:6,000 (in a central area of about 21 square miles) and 1: 12,000 (in the surrounding area of about 15 square miles). The field data have shown that after the structure was formed, the region was eroded to one of very low relief, with hills from a few meters to 20 meters high. Erosion removed all debris from the rim but did not fill the crater. Later deposition of the Chattanooga Shale during Late Devonian time then filled the crater and covered the surrounding area. Two major rim folds with vertical axial planes concentric to the crater rim suggest strong horizontal compression at shallow depths during formation of the structure. Petrofrabric studies of the deformed rim rocks show that the number of twin lamellae and amount of microfracturing parallel to the cleavage increase toward the crater. However, no trace-element anomalies, abnormal mineral variation, or high-pressure polymorphs have been found in laboratory studies.

Pseudotachylite in Vredefort dome, South Africa

Pseudotachylite occurs in net veins in the older Precambrian granite core of the Vredefort dome. According to H. G. Wilshire, who has studied the pseudotachylite because of its possible origin by meteorite impact, concludes that the microscopic fabric of the pseudotachylite and its inclusions indicates that little fusion, if any, has taken place, and that shearing was probably a dominant factor in the rounding and comminution of rock fragments. The survival of perthite derived from granite indicates that the prevailing temperature during formation of the pseudotachylite was less than about 650°C. Rock bursting into dilated zones caused by movement along irregular fault planes is postulated as a cause of formation of breccias in which the pseudotachylite is found; further movement in and along the breccia zones caused mylonitization of the rock and injection of mylonite into fractures separating the rock fragments.

Crater studies at White Sands, N. Mex.

The impact of a missile on water-saturated gypsum lake beds produced a crater about 30 feet across and 7 feet deep. H. J. Moore and R. V. Lugn found that the morphology and ejecta of the crater are similar to those of large natural craters produced by meteorite impact and of some craters produced by explosives. The stratigraphic sequence is overturned in the ejecta, and the beds are locally folded near the crater walls. Secondary impact features range from implanted fragments to craters containing fragments, and to craters which do not contain fragments. The volume of the main crater is about six times larger than one produced by a missile impact in dry alluvium, although the kinetic energies and angles of impact of the two missiles were nearly the same. The difference in size of the two craters is partly related to difference in the strengths of dry and wet materials, because the strength of water-saturated materials is nearly constant at elevated confining pressures, while the strength of dry materials increases with increasing pressure. Hence, larger craters may be produced in wet targets than in dry ones by projectiles with the same kinetic energies and velocities. Calculations of the effective target strengths for the two craters using the Charters-Summers' theory of impact-crater formation yield reasonable values for their deformation strengths.

Meteorite craters at Odessa, Tex.

Study of the meteorite craters at Odessa, Tex., by C. H. Roach, S. P. Lassiter, and T. S. Sterrett shows that rocks to a depth of about 130 feet below the main crater have significantly lower concentrations of mercury than do stratigraphically equivalent rocks at a distance of 1.1 miles. The depletion of mercury in rocks at shallow depths beneath the crater may have resulted from (1) processes caused by the impact event that formed the Odessa meteorite craters, or (2) postimpact leaching by vadose waters percolating through the lens of brecciated rocks beneath the crater. Additional chemical studies are in progress to try to evaluate the reasons for the depletion or redistribution of mercury in the affected rocks.

Collection of meteorite material, Meteor Crater, Ariz.

The first systematic collection of meteorite material around Meteor Crater, Ariz., in which the location of each find was recorded and surveyed, has been completed by D. J. Milton and A. J. Swartz. About

90 specimens ranging in weight from a few grams up to 15 kilograms were collected.

Hydrodynamic modification of large lunar craters

The history of a circular crater in a highly viscous medium is derived from the hydrodynamic equations of motion by Z. F. Danes. The variation in shape of the crater in the course of time is expressed as a function of a time constant, T, that involves viscosity and density of the medium, acceleration of gravity, and radius of the crater lip. Correspondence between theoretical crater shapes and the observed ones is good. However, the time constant, T, is suprisingly short if commonly accepted viscosity values are used. Thus, if the present analysis is valid and if lunar crater ages are of the order of 10^9 years, lunar rock viscosities must be of the order of 10^{25} to 10^{26} poises. If viscosities of lunar rocks were around 10^{21} to 10^{22} poises, the ages of large craters would have to be only 10^4 to 10^7 years.

COSMOCHEMISTRY AND PETROLOGY

Cosmic chemistry and petrology include the investigation of tektites, impactites, meteorites, and cosmic dust.

TEKTITES

New data on some Ivory Coast tektites

The physical properties and chemical composition of some Ivory Coast tektites have been studied by E. C. T. Chao, Frank Cuttitta, M. K. Carron, Charles Annell, and Priscilla Mount. Bulk indices of refraction range from 1.5156 to 1.5217±0.0004, and bulk specific gravities range from 2.428 to 2.502±0.005. These tektites resemble the southeast Asian tektites in their internal flow structures, ranges of physical properties, and frequent occurrence of siliceous glass inclusions. Chemical analysis of the major and minor elements in 7 Ivory Coast tektites shows that the group is chemically distinct from other tektites, being characterized by rather low SiO_2 content (67.2–69.1 percent), relatively high Al_2O_3 content (16.1–16.8 percent), unusually high MgO/CaO ratios (about 3.1), and a content of Na_2O slightly greater than that of K_2O. The Na_2O/K_2O ratios for the Ivory Coast tektites are greater than unity, whereas these ratios for all other tektite groups are less than unity. The Ivory Coast tektites are high in content of Co (19–25 parts per million), Ni (101–167 ppm), Cr (260–375 ppm); particularly high in content of Pb ($<$10–18 ppm), Cu (13–21 ppm), and Ga (14–23 ppm); but low in content of Zr (range, 108–120 ppm; average 116 ppm). Although these tektites resemble some javanites in petrographic and physical properties, the new analyses suggest that the Ivory Coast tektites form a chemically distinct group.

Metallic spherules in impactites and tektite glass

Electron-microprobe analyses by Robin Brett indicate that Ni-Fe spherules in impactite glass bombs from the Meteor Crater area, Arizona, contain 20 to 65 weight percent Ni. Spherules from impactite glass at Wabar, Saudi Arabia, contain 8 to 41 weight percent Ni. The parent meteorites contain 7 to 8 weight percent Ni. The glass surrounding the spherules is enriched in Fe; the Meteor Crater glass contains 12 to 27 weight percent Fe, and the Wabar glass 0 to 10 percent. Spherules in philippinite and indochinite tektites contain 1 to 3 and 4 to 6 weight percent Ni, respectively. The glass surrounding tektite spherules is not enriched in Fe. Brett proposes that spherules in impactite glasses were partially oxidized prior to or during incorporation into impactite bombs. The iron oxide, almost Ni-free, diffused into the glass, depleting the metal in Fe and enriching the glass. Dolomite and water may have contributed to the oxidation at Meteor Crater. Spherules in tektites probably were not oxidized because the tektites were formed in an atmosphere with extremely low fugacity of oxygen. A less likely alternative is that the spherules were incorporated into the tektite glass instantaneously so that oxidation was prevented.

Multivariate analysis of geochemical data on tektites

Fundamental problems in the origin of tektites are (1) estimation of the composition and nature of the parent material from which they were derived, and (2) the nature and complexity of the system of processes that led to their formation. Estimates of correlation among various chemical constituents in tektite specimens are thought to bear on these problems, but the observed correlations are subject to restraints imposed on the data array by its numerical structure—in particular the constant item-sum and the forms of ratios and other functional variables of interest.

A. T. Miesch, E. C. T. Chao, and Frank Cuttitta have studied chemical and spectrographic analyses and physical-property measurements on 21 bediasites from east-central Texas. Correlation coefficients derived from these data were tested against correlations derived from closed arrays of random deviates. Many of the correlations that were apparently significant when tested against zero are no greater than can be attributed to the constant item-sum (closure) effect. Other correlation coefficients near zero are highly significant and are indicative of petrogenetic association. Correlations involving either major or minor elements that have low relative deviations appear to be affected by closure to an important degree. A measure obtained on adjustment of correlation coefficients for the possible effects of closure and the forms of functional variables can be tested for significance against zero. This measure is used in factor-analysis procedures that lead to a geologic model that accounts for the covariance relationships in the bediasite data. Three geologic factors required in the model are believed to be (1) the amount of chondritic meteoritic matter incorporated into the principal parent material of the bediasites, (2) the degree of magmatic differentiation in the principal parent material, and (3) the effects of volatilization and other processes acting during tektite formation.

Petrochemical groupings of tektites

D. B. Tatlock has found that bediasites, indochinites (including thailandites), and austral-philippinites (including javanites) are each effectively separated on a modified ACF plot into normal, high-ferromagnesian, and low-alumina groups. There is little superposition of groups from one major tektite locality to another. The normal groups, into which most tektites fit, are marked by low standard deviations of all major components. They also display significant negative correlation between excess Al_2O_3 (normative corundum) and the ratio $K_2O + Na_2O : FeO + Fe_2O_3 + MgO + MnO - TiO_2$, which suggests that there has been volatilization of the alkalis.

Significant correlations and ratios among various pairs of major constituents are common to both tektites and unaltered igneous rocks, but not to sedimentary units. Bediasites and Australasian tektites are probably derived, by differentiation resulting from impact fusion, from source materials of rather narrow compositional range. It is improbable that the source material of tektites was terrestrial because of the regularities and similarities of differentiation trends among tektites in two strewn fields of widely different age.

METEORITES

Cohenite in meteorites

A study by Robin Brett, part of a continuing investigation of the stability and occurrence of meteoritic minerals, indicates that cohenite—$(Fe, Ni)_3C$—is found almost exclusively in meteorites containing from 6 to 8 weight percent Ni. On the basis of Fe–Ni–C phase diagrams and kinetic data, it is possible to explain occurrence of cohenite within this narrow composition range as a low-pressure metastable phase, and the nonoccurrence of cohenite outside the range from 6 to 8 weight percent Ni. Brett proposes that cohenite which formed in meteorites containing less than 6 to 8 weight percent Ni decomposed to metal plus graphite during cooling, and that cohenite cannot form in meteorites containing more than 8 weight percent Ni. The presence of cohenite in meteorites cannot be used as an indication of pressure of formation. However, the absence of cohenite in meteorites containing the assemblage metal + graphite requires low pressures during cooling.

Sphalerite composition as a possible paleobarometer for meteorites

Calculations by Priestley Toulmin 3d, based on experimental work by P. B. Barton and Toulmin on the system Fe–Zn–S, indicate that the iron content of sphalerite in equilibrium with iron and troilite is strongly influenced by total pressure, and is relatively insensitive to temperature. This suggests that the compositions of sphalerite in a meteorite might give useful information regarding pressure of formation, and hence the minimum size for the parent body of the meteorite.

Minor elements in some achondrites

M. B. Duke reports that emission spectrographic analyses of whole meteorite samples and of plagioclase and pyroxene separated from basaltic meteorites show variations consistent with an origin of these meteorites by magmatic differentiation. Fractionation of elements between pyroxene and plagioclase is similar to that observed in terrestrial basalts. Moreover, it appears that the parent material had a U-K ratio very close to that suggested for the Earth's mantle. On the other hand, analyses of minor elements in pyroxenes from hypersthene achondrites are similar to those for basaltic meteorites, whereas those from pyroxenes in a diopside achondrite and in the Sherghotty basaltic achondrite are different, especially in their contents of siderophile elements.

Cosmic dust

M. B. Duke and M. H. Carr have begun preliminary work to determine the characteristics of cosmic dust by examining particulate matter collected at high altitude within the atmosphere. They are also participating in experiments designed to collect cosmic dust above the atmosphere. Because the size distribution of cosmic dust is such that only very small particles can be collected, analytical facilities specifically designed for the handling of small particles—ultraclean laboratories—have been built by the U.S. Geological Survey in Washington, D.C., and Menlo Park, Calif. In addition, electron-microscope and electron-microprobe facilities in Washington, D.C., have been improved.

STUDIES OF IMAGES MADE FROM SPACECRAFT

RANGER

Preliminary geologic analysis of the Ranger VIII and IX photographs by the U.S. Geological Survey appeared as part of the experimenters' report [51] published by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. The analysis includes studies of the general nature and topography of the lunar surface, and intermediate- to large-scale geologic maps. The map of largest scale was used to show how geologic considerations may be used in planning scientific tasks to be executed by astronauts in the early Apollo landings on the Moon.

Investigation of the geology and fine structure of the lunar surface is being continued, using the wealth of data returned to the Earth by the three successful Ranger missions. Results of several individual studies are described in the following paragraphs.

Size-frequency distribution of craters

N. J. Trask has made a study of the size-frequency distribution of the craters on all three sets of Ranger photographs. The frequencies of craters less than approximately 100 meters in diameter are the same on the 3 sets, within reasonable limits. The floor of Alphonsus is closely similar to geologic units that are clearly older than the mare surfaces, and it is probably older than the maria themselves. The similarity of crater frequencies on surfaces of differing ages is consistent with the idea that repeated cratering has produced a steady-state surface on which crater frequencies do not change with time for craters below a given size. A large proportion of craters with diameters of between 1 and 3 kilometers is observed on both the Ranger photographs and superior earth-based photographs. The large number is thought to be due to the addition of large numbers of secondary craters to the total crater population.

Comparison of lunar, terrestrial, and model craters

H. J. Moore has compared the smallest craters photographed on the last frames of Ranger IX with craters of the same size produced by chemical and nuclear explosives and missile impacts in natural materials. If the majority of lunar craters are formed by impact, the comparison suggests that the lunar surface materials are weakly cohesive to noncohesive. There are no large, sharply defined blocks around the lunar craters, such as occur in profusion around chemical-explosion craters in such materials as basalt. A few low, lumpy structures, seen on the walls and rims of the lunar craters, resemble isolated low lumps found around terrestrial craters formed by missile impacts in weakly cohesive materials. The slopes of the walls of all the lunar craters appear to be less than 38°, in contrast to slopes of 60° in the walls of terrestrial craters in weakly cohesive alluvium. The low slopes of the lunar craters are consistent with the interpretation that the surface layer consists of noncohesive, fragmental material lying at its natural angle of repose.

Craters and geologic interpretation of the lunar surface

M. H. Carr has studied the structure and texture of the floor of Alphonsus. He discriminates five geologic units, largely on the basis of characteristic size-frequency distributions of craters. Many of the craters are alined along lineaments and are clearly of internal origin. Dark-halo craters occurring along lineaments appear to be examples of volcanic craters with a surrounding blanket of pyroclastics. Other crater deposits, as well as blanket deposits on the floor, are interpreted as volcanic ejecta. Lineaments, widespread on the floor, correspond to the directions of the lunar grid and to the direction radial to the Mare Imbrium basin. The distribution of the lineaments is not the same at all scales, however.

Lunar patterned ground

A distinctive pattern of gentle ridges or mounds and intervening troughs is widespread on the final pictures of each Ranger mission and may occur over most of the lunar surface. The ridges and troughs tend to be parallel to much larger regional lineaments on the Moon. E. M. Shoemaker has suggested that this pattern be termed "lunar patterned ground," and attributes it to joints and fissures in material that underlie the lunar surface at shallow depths. Jostling of the underlying blocks would tend to heap up the relatively cohesionless fragmental surface material toward the centers of the joint blocks, and to move material away from the edges of the blocks.

Photogrammetric studies

The U.S. Geological Survey is investigating the photogrammetric reduction of selected stereoscopic pairs of Ranger photographs to obtain control for the compilation of detailed topographic maps by photometric methods. This control is required in order to determine the local photometric function of small areas on the lunar surface and to connect photometrically derived profiles in the direction normal to the phase angle plane. A general study of the photogrammetric reduction of Ranger pictures has been

[51] Jet Propulsion Laboratory, 1966, Technical report 32–800, pt. II: Pasadena, Calif., March 15, 1966.

carried out by J. D. Alderman, W. T. Borgeson, and S. S. C. Wu.

As a part of the photogrammetric investigations, H. J. Moore and R. V. Lugn set up an experimental stereo model with an ER–55 plotter and, using two A-camera photographs from the Ranger VIII mission, studied the problems of design and use of an anaglyphic projection instrument suitable for analysis of Ranger photographs. The preliminary photogrammetric results reported here are entirely experimental in nature but represent an approximate solution of the topography of the area studied.

Large-scale geologic maps

A series of geologic maps has been constructed from the Ranger VIII and IX photographs at a variety of scales. D. J. Milton and D. E. Wilhelms have used a relatively distant Ranger VIII photograph to prepare a map at a scale of approximately 1:500,000 that shows in greater detail the distribution of the regional units mapped earlier at scales of 1:1,000,000. J. F. McCauley mapped the floor of the large crater Alphonsus at a scale of approximately 1:100,000. The additional detail that can be mapped at this larger scale requires the definition of new stratigraphic units not resolvable on the 1:1,000,000 scale maps. A geologic map of the small area in Mare Tranquillitatis covered by the topographic map of Moore and Lugn was constructed by N. J. Trask. He plotted the geology directly from the stereo model of the lunar surface produced by the ER-55 plotter. All the geologic units recognized on the mare surface at this scale are subdivisions of craters. H. H. Schmitt used the final B-camera frame of Ranger VIII to prepare a detailed map of crater units at a scale of approximately 1:10,000. He then used the map to plan two hypothetical traverses by astronauts from a landed LEM. The traverses were designed to enable the astronauts to sample a diversity of crater materials and to examine a variety of structures observable on the ground.

SURVEYOR

Conditions necessary for effective depth perception

Surveyor television investigations by E. C. Morris, H. E. Holt, and R. M. Batson have been concerned with the development of techniques for extracting photogrammetric, photometric, and geologic information from the television pictures to be received from the Surveyor cameras on the lunar surface. Experiments have been conducted to determine the maximum amount of convergence (the angle between the optic axes of the cameras) that can be accommodated in compiling topographic maps by photometric techniques from Surveyor photography. The experiments have shown that usable stereopsis, or capacity for depth perception, is dependent upon surface roughness, direction of illumination, and convergence. The rougher the surface, the less the convergence which can be tolerated. On relatively smooth models, degeneration of stereopsis began as convergence approached 40°, and at 55° convergence only 50 to 60 percent of the models could be measured to required accuracy. Stereopsis is degraded when the camera base rises on the plane of illumination and convergence is large.

Preparation of mosaics

Techniques for mosaicking pictures received from the Surveyor spacecraft on the Moon were developed by R. M. Batson and K. B. Larson, for use immediately after receipt of the data for further planning while the mission is still in progress.

Mapping techniques for use with Surveyor photographs

H. E. Holt and S. G. Priebe have developed techniques for applying photoclinometric mapping to the Surveyor television pictures. The first 7 Surveyor spacecraft, which will be engineering missions, will be launched with only 1 television camera and will lack the stereoscopic and photogrammetric capabilities of the later, 2-camera, science spacecraft. The new methods will permit the preparation of topographic base maps for scientific analysis, from the images received from the single-camera Surveyor spacecraft.

Experiments by H. E. Holt have demonstrated that the plane of polarization and the degree of the polarization of light reflected from the lunar surface can be determined by using three oriented polarizing filters in the filter wheel of the Surveyor television camera. Sensitivity and accuracy of the detection technique are dependent upon the stability and dynamic range of the camera-recorder systems. The technique can detect the presence and orientation of polarized-light components comprising as little as 5 percent of the reflected light. The polarizing properties of the surface materials determined by means of the television images will be used as a discriminating tool for the geologic analysis of the lunar surface.

OTHER STUDIES OF SPACECRAFT IMAGES

Interpretation of Luna 9 photographs

E. M. Shoemaker, R. M. Batson, and K. B. Larson (r0715) have made a preliminary analysis of the data from the Soviet Union's Luna 9 space capsule. The surface of the Moon portrayed in the Luna 9 pictures appears to be composed almost entirely of two elements—craters and rock fragments. Recognizable craters range in size from about 2 centimeters to several tens of meters. The smallest craters are about 25 times smaller than the smallest craters previously observed in Ranger pictures. Most of the craters observed in the Luna 9 pictures are relatively shallow; slopes of the crater walls range from less than 7 percent to more than 27 percent. The largest craters have sharply defined or rounded raised rims, but many of the small craters seem to lack raised rims. Angular rock fragments that litter the scene range in size in the near field from a few millimeters (the limit of recognition) to several tens of centimeters in greatest dimension. The most prominent fragment in the fields of view is 10 to 20 cm wide and 10 cm high. The coarseness and angularity of the fragmental debris observed in the Luna 9 pictures contrast rather strongly with the relatively smooth appearance suggested by the Ranger pictures of highest resolution. However, radar observation of the Moon in millimeter wavelengths indicates that the average roughness increases rapidly between 1 meter and a few centimeters resolution. Analysis of the Luna 9 pictures will have importance not only to the Surveyor project but also to the Apollo program.

Lunar Orbiter

Selection of target areas for the first Orbiter mission was based primarily on data contained in the U.S. Geological Survey terrain map of the lunar equatorial belt (latitude $\pm 10°$, longitude $\pm 60°$), at a scale of 1:1,000,000, and on the geologic maps at the same scale. The ground rule used in the selection was that mission A would be distributive in nature and would sample as many terrain types as possible. Design specifications for the mission require that each of the recommended target sites consist of an area approximately 93 by 36 kilometers in the low-resolution stereoscopic mode (approximately 10-meter ground resolution), and of an area 16 by 64 km nested in the center of each of these areas in the monoscopic high-resolution mode (approximately 1-m ground resolution).

STUDIES RELATED TO MANNED LUNAR EXPLORATION

The U.S. Geological Survey's manned lunar-exploration studies include geologic training of the astronauts, and investigation of methods and equipment applicable for training under simulated lunar conditions and for geological and geophysical exploration by astronauts on the Moon.

Astronaut training

The first three groups of astronauts have completed their geologic training and are qualified as capable geologic observers. This year the field training emphasized volcanic features at the following localities: Medicine Lake area, California, (leader, C. A. Anderson); Katmai, Alaska (leader, R. L. Smith); Iceland (leaders, Dr. Sigurdur Thorarinson and Dr. Gudmundar Sigvaldson); Zuni Salt Lake crater (leaders, A. H. Chidester and R. D. Regan); and Pinacate Mountains, Sonora, Mexico (leader, Prof. R. H. Jahns). Geology lectures held at the Manned Space Center, Houston, Tex., included the following topics: large-scale structure of the Earth, by W. M. Cady; geophysics, by M. F. Kane; lunar cold traps and the lunar atmosphere, by Kenneth Watson; and lunar geology, by Harold Masursky. A 37-minute 16-millimeter color-sound astronaut training film entitled "Hawaii Volcanoes Astronaut Field Trip," prepared under H. G. Stephens, is available for public showing.

Field methods

Much attention is being directed toward methods for efficient geologic exploration of the Moon. Several test areas, which encompass a variety of geologic features, have been established within an 80-mile radius of Flagstaff, Ariz. A recently completed audio-video system simulates an Earth-Moon communications link and enables the monitoring of activities at remote test sites from the control center in Flagstaff. Test subjects (geologists and geophysicists), acting the role of geologically trained astronauts on the lunar surface, have explored preselected test areas while maintaining communications with a test director at the control center. With the aid of radioed descriptions and televised images, geologic maps were compiled in the control center, using aerial photographs and coordinate-grid paper. Information resulting from petrologic studies made at the site, when added to that plotted during the traverses, resulted in geologic maps that are adequate for an understanding of the geologic conditions at the site and its surroundings. Apollo-type missions will restrict exploration to the few selected features that can be reached on foot. Although space-suited geologists cannot traverse terrain nor perform geological operations as rapidly as a geologist in shirt sleeves, techniques of automatically locating the astronaut, plus data handling and map compilation at a remote center, will largely offset these restrictions.

Observatory for magnetic-field studies

A geophysical observatory was established about 10 miles northwest of Flagstaff, Ariz., for study of the earth's magnetic field and to determine flux effects on that field by possible lunar magnetism. A three-component U.S. Coast and Geodetic Survey world-net standard seismometer was installed in the observatory. An FM data telemetry link to offices in Flagstaff will permit study and trial of a seismic system analogous to that a single station location that may someday be transmitting from the lunar surface.

Equipment testing

A stereometric film camera, one of the principal exploration tools for the Apollo program, has been designed and constructed to permit evaluation of specifications for an Apollo film camera that will be developed by industry. It is one of several hand-carried tools constructed by the U.S. Geological Survey and now undergoing evaluation in the field by space-suited test subjects. Analytical equipment of various types is being evaluated in terms of its possible geological and geophysical application to lunar and planetary exploration. The several pieces of analytical equipment that have been tested in the field and that show potential value include: petrographic and binocular microscopes, with and without attached television camera; a miniaturized portable thin-section grinder; an X-ray diffractometer (with miniature goniometer); a device to determine the magnetic susceptibility of rocks; a 12-channel refraction seismograph; gravimeters; magnetometers, including one extended from a roving vehicle on a boom to give continuous readings; and a natural gamma-ray spectrometer. Several other analytical systems are being tested.

GEOLOGIC USE OF REMOTE-SENSING DATA

The U.S. Geological Survey is taking part in study of the feasibility of using remote-sensing devices mounted in aircraft and in earth-orbiting spacecraft as tools for the study of cartography, geography, geology, and hydrology.[52] The remote-sensing tools under consideration utilize portions of the electromagnetic spectrum and the force fields; they include black-and-white and color photography, radar and infrared imaging and nonimaging systems, microwave imagers and radiometers, and magnetometers and gravimeters. Many of these tools are well developed, but their capabilities for use in aircraft or spacecraft are untested. Data obtained from small areas by the various sensors mounted in low-flying aircraft will be evaluated by Survey scientists by mapping on the ground or by other conventional methods. Studies of larger areas, flown across by high-altitude aircraft and space vehicles, will be made largely by comparison of known geology with the results of the remote-sensing investigations.

Some of the major geologic and hydrologic problems of worldwide scope which may be amenable to study by use of remote sensors are: (1) convective heat flow in the earth's crust; (2) lateral shift in fault zones of the world; (3) ecology and distribution of reef-building organisms; (4) magnetic variations in the earth's crust; (5) metallogenic provinces; (6) seasonal variations of sediment loads, and sediment distribution, in the world's major rivers; (7) measurement of gross evapotranspiration; (8) identification of areas of important ground-water discharge; and (9) runoff and water-retention characteristics of drainage basins.

The following brief statements describe representative examples of remote-sensing methods and instruments now being studied.

PHOTOGRAPHIC STUDIES

Effect of angle of illumination on aerial photographs

R. J. Hackman has studied time-variant phenomena and their effects on image interpretation. He found that some small terrain features on the Moon and some on the Earth are better represented in photographs taken at low angles of solar illumination than in those taken at high angles, but that tonal qualities are better at high angles of illumination. Such variations may also seriously affect the interpretation of data from imaging systems such as side-looking radar.

Studies of photographs taken from Gemini spacecraft

Approximately 200 hyperaltitude color photographs from the Gemini IV, V, VI, and VII space missions have been distributed to geologists for identification, study, and comment. Initial replies indicate that such photographs can be of great utility in reconnaissance geologic mapping of the gross structural and lithologic features of little-known regions, and in compiling small-scale maps.

R. W. Tabor found that certain soils and rock types in the southwestern United States can be mapped from such photographs with considerable accuracy.

James Seitz, USGS/USAID, La Paz, Bolivia, annotated the regional geology and geography of the Bolivian Altiplano on a single photograph of the

[52] Most of these studies are being conducted in cooperation with the Natural Resources Program of the National Aeronautics and Space Administration (NASA).

area extending between Lake Titicaca and Lake Poopo and covering approximately 75,000 square kilometers.

R. F. Johnson discovered a lineament, found later to be a large wrench fault, in the Precambrian of northwestern Saudi Arabia. Although the area was also covered by a photomosaic at 10 times the scale of the Gemini photo, the fault was not apparent on the mosaic.

Analyses of multiband photography

R. E. Wallace compared enhanced multiband photographs with black-and-white and color aerial photographs of the Carrizo Plains area of the San Andreas fault zone, California. He found that the multiband photograph was more useful than the color photographs in distinguishing between several types of surficial materials, each having different particle size.

J. G. Vedder and E. W. Wolfe compared an enhanced multiband aerial photograph of the Caliente Range with a color photograph of the same area. The color photography was considered extremely valuable for mapping unknown terrain where rocks have contrasting colors. The multiband photograph indicated that certain rock types, such as white arkosic sandstone, and olivine basalt in flows, were markedly enhanced, suggesting that the method can be used as an analytical tool in the study of stratigraphic facies.

Remote sensing of glacier data

Airborne multispectral photography and other tests were carried out at South Cascade Glacier, Wash., as part of a Federal interagency program of NASA, the Office of Naval Research (ONR), the Air Force Cambridge Research Laboratory, and the Geological Survey, to investigate the usefulness of spacecraft for obtaining glaciological data. M. F. Meier, R. H. Alexander (ONR), and W. J. Campbell (r2062) describe the studies, which were made with nine-lens multispectral cameras, cartographic cameras with color and color infrared film, thermal infrared scanning radiometers, profiling microwave radiometers, a side-looking radar, and a radar scatterometer. The studies were made on flights in both fall and spring. Correlative meteorological and photometric measurements were made on the ground. Near-infrared photography was found to be fairly effective in distinguishing snow from ice and old firn, whereas short-wavelength visible light is better for distinguishing ice structures and moraine. Wetness contrasts are emphasized by the infrared. The color-infrared film shows detail such as subtle moraine structures very clearly. Crevassed areas, moraines, and other linear structures show up clearly on radar images, and gross textural differences between glacier ice, old snow, and land are apparent even when both are covered with a thin new snow layer. The thermal infrared and microwave radiometry, perhaps of greatest potential, have not yet been completely analyzed.

Hydrologic applications of photography

H. E. Skibitzke and C. J. Robinove have studied color and infrared-color photography to determine the applications of certain airborne remote-sensing techniques to lake surveying. They assessed the depth penetration of water by photographing, with color film and various filters, targets submerged at a range of depths. They also determined the diurnal variation in temperature over land and water surfaces at Lake Cachuma, Calif., with an airborne infrared radiometer. Color and infrared-color photography were used to map the mixing of pollutants in the Great Lakes, to identify water-surface color and bottom features of Great Salt Lake, Utah, and to map the staged eutrophication of Florida lakes. Similar studies were conducted at the prairie potholes of North Dakota, Sand Hill lakes of Nebraska, the Salton Sea in California, and some lakes in Minnesota.

INFRARED AND ULTRAVIOLET STUDIES

Infrared imagery of San Andreas fault

In another trial of remote sensing in study of the San Andreas fault system, R. E. Wallace and R. M. Moxham found that infrared images (in the 8–13-micron band) clearly display the trace of the San Andreas fault system through most of the Carrizo Plain area of California. Visibility of the fault in the infrared imagery is affected by variations in soil moisture caused by the water-barrier characteristics of the fault zone, and by differences in vegetation related to soil moisture and microtopography. Among other features recognized are ancient segments of stream channels, offset by movement along the fault; landslide terrain; and numerous soil units and Tertiary bedrock units. Imagery obtained 1 to 2 hours before sunrise is considered most useful for the fault studies.

Infrared surveys of Taal Volcano, Luzon, Philippine Islands

R. M. Moxham and Arturo Alcaraz (r2063), working in cooperation with the U.S. Agency for International Development and the U.S. 13th Air Force, made infrared scanner (8–14-micron) surveys of the Taal Volcano area, 2 weeks after the September 1965 eruption. Two principal areas of abnormal thermal activity were defined: (1) a fumarole area which has been active for many years on the north flank of the volcano's main (1911) crater, and (2) anomalies around the summit and on the southeast flank of Mount Binintiang Malaqui on the northwest tip of the island. Historical records indicate that Mount Binintiang Malaqui last erupted in 1707. Though some hot springs and fumaroles were previously known, the infrared surveys indicate that the thermal activity at this crater may be more widespread than previously supposed.

Ultraviolet absorption and luminescence investigations

According to W. R. Hemphill, (1) reflectance differences among many rock types are greater in the ultraviolet part of the electromagnetic spectrum than in the other parts thus far investigated; (2) linescan images which record reflected ultraviolet energy show some features, such as craters, in striking contrast to their surroundings; and (3) images showing the distribution of luminescent minerals have been produced at distances greater than 200 feet by use of a newly developed ultraviolet imaging device.

Studies of Nimbus I imagery

James Burns, Mario Conti, and Edward Hasser studied imagery from the Nimbus I high resolution infrared radiometer (HRIR) and advanced vidicon camera systems (AVCS), respectively. Burns and Conti found that the infrared imagery was useful in detecting certain features, such as ice sheets, by thermal patterns. Hasser found that recognizable tonal variations on vidicon photography show little correspondence to bedrock geology and structure.

RADAR STUDIES

Synoptic view of San Andreas fault zone

Side-looking radar imagery in the K-band was obtained of an area about 400 miles long and 15 miles wide along the San Andreas fault zone. The images provide a synoptic view of the area in one continuous strip, and linear features such as the San Andreas and branching faults show with especial clarity because of the "side-lighting" effect. R. E. Wallace reports that a northeast-trending set of lineaments visible in the radar images may represent a fault set not clearly recognized in the past.

Detection of surface features, Hart Mountain area, Oregon

G. W. Walker recognized that side-looking radar imagery of the Hart Mountain area reveals a large number of the structural features (mainly faults) that had been found by earlier surface mapping. Among surficial features, water-saturated sediments were easily distinguished from "dry" sediments on radar imagery.

Stratigraphic and structural studies along Oregon coast

P. D. Snavely, Jr., and H. C. Wagner found that radar imagery effectively "defoliated" the Oregon coast, enhancing the topographic and tonal expression of certain Tertiary rock units. Miocene basalt flows show the highest reflectivity, as expressed by the lightest tones; sandstones give intermediate tones; and marine mudstones give the lowest radar returns of any of the Tertiary rocks studied. Faults and lineaments that cannot be identified on conventional black-and-white aerial photography were recognized on radar imagery.

Radar imagery of volcanic terrain

Radar imagery of volcanic terrain of the High Cascade Range, Oreg., examined by D. A. Swanson, clearly shows viscous dacite lava flows and domes, and cinder cones and craters. The radar data do not, however, indicate differences between such rock types as andesite and basalt (which have similar composition and topographic characteristics). Fault zones, lakes, and water-saturated meadows stand out as black areas.

Radar imagery of Jackson Hole, Wyo.

Side-looking radar imagery of the Jenny Lake area, Jackson Hole, Wyo., was studied by A. B. Campbell who found that such imagery was especially effective in distinguishing surficial features (moraines, outwash plains, knob-and-kettle areas) of glacial origin as well as certain fault zones.

OTHER STUDIES

Magnetometer experiments

Isidore Zeitz, L. C. Pakiser, E. R. King, W. H. Geddes, and E. G. Lidiak analyzed a series of transcontinental aeromagnetic profiles across the United States, parallel and spaced at 5-mile intervals. They recognized anomalies with spatial wavelengths of several tens to several hundreds of miles and amplitudes of 1,000 gammas or more. The anomalous patterns are spatially related to distributions of values for seismic velocity and for heat-flow distributions that evidentally originate in the deeper portion of the crust or in the upper mantle. Extrapolation of these data to orbital altitudes indicates that such anomalies can be recognized and mapped from spacecraft. Furthermore, weak near-surface anomalous patterns should be filtered out at space altitudes, so that only relatively strong deep crustal anomalies will be recognized.

Surface geologic studies related to remote sensing

In preparation for remote sensing from aircraft in the northwestern Yellowstone Park area, Wyoming, K. L. Pierce made a detailed chart of the properties of surficial materials that are considered critical for remote-sensing imagery. The chart describes the following aspects of the surficial material: texture at and below the surface, moisture-retention characteristics near the surface, thickness, slope and local relief (that is, surface roughness), composition, compaction, and vegetative cover. The chart will be used as a reference in comparison of radar, microwave, and infrared images of the area.

J. D. Friedman made detailed compositional studies of older aa and younger pahoehoe lavas in flows of porphyritic olivine basalt at Pisgah Crater, Calif., to determine what kind of analytical information is most useful for infrared interpretation. Chemical and mineralogical differences between the two lavas are slight, but the surface of the aa lava was richer in Fe_2O_3 and MnO than the pahoehoe. Iron and manganese occur as desert varnish on both rock types, but are more abundant on the aa because it is older and because it has a greater surface-to-volume ratio. The minor variations in composition recorded in this study are considered too small to affect the thermal emissivity and inertia of the rock. The wider ranging differences in surface-to-volume ratio and in vesicularity are more significant.

Potential for cartographic application of remote-sensing data

Winston Sibert and L. E. Starr made cartographic studies of a Gemini VII photograph of the Cape Kennedy area by comparing it with the corresponding portion of the Orlando, Fla., topographic map (scale, 1:250,000) published in 1955 and revised in 1962. The photograph clearly showed new highways, roads, airports, and urban development, and indicated that space photography will have great value in revision of published maps and in new mapping.

EARTHQUAKE STUDIES

GEOLOGIC INVESTIGATIONS

SAN ANDREAS FAULT SYSTEM

A program of geologic analysis of the San Andreas fault system was begun this year as part of the Western States earthquake belt program. Of particular concern has been the determination of total amount of displacement and of rate of movement on the fault, and the regional pattern of the San Andreas and related faults.

Late Cenozoic strike-slip movement

Evidence indicative of large-scale strike-slip in late Cenozoic time has been gathered by J. G. Vedder in the Caliente and Temblor Ranges of south-central California. There Vedder finds that upper Cenozoic marine and nonmarine sedimentary rocks on opposite sides of the fault represent sharply contrasting depositional environments. He suggests that these dissimilar rock assemblages have been brought into juxtaposition by displacements of more than 30 miles, and perhaps as much as 80 miles, since the beginning of late Miocene time. Analysis of paleoslopes and directions of sediment transport have proven extremely significant in arriving at this interpretation.

Quaternary strike-slip movement

T. W. Dibblee, Jr., has found evidence of large-scale right-lateral strike slip along the San Andreas fault since early Pleistocene time that amounts to possibly as much as 20 miles. Evidence for this movement was found in the Shandon and Orchard Peak quadrangles of southern California, where terrestrial sediments of Pleistocene(?) age are composed of siliceous shale debris southwest of the San Andreas fault, whereas northeast of the fault the sediments of that age contain sandstone and shale debris derived from the underlying sandy bedrock. The siliceous shale debris thus could not have been derived from bedrock now situated immediately east of the fault, but probably was derived from extensive exposures of siliceous shales of the Monterey Formation that now lie northeast of the fault far to the southeast.

Recurrent movements in Recent times

In the Carrizo Plain west of Bakersfield, Calif., where the surface of the ground was broken during the 1857 earthquake, R. E. Wallace has interpreted that during approximately the last 10,000 to 20,000 years, displacements occurred over and over again along the same (1857) strand of the San Andreas fault. This strand follows a zone which for many miles is no more than 100 feet wide, in comparison to the entire fault zone which may be as much as a mile wide. An implication of this finding is that the potential for severe damage should be recognized in design and construction where manmade structures must cross strands of the fault known to have been broken in relatively recent time. The line of breaks formed during the 1857 and 1906 earthquakes thus should be avoided, recognizing, however, that movement may also occur in the intervening segments of the fault or on subsidiary faults.

Enigmatic movement directions

The San Andreas fault system is a complex of fractures not yet well understood. The Nacimiento fault, a major structure and an enigma in the fault system, was mapped in the San Rafael Range by J. G. Vedder, H. D. Gower, H. E. Clifton, and D. L. Durham and was found to have thousands of feet of stratigraphic throw, but evidence of strike slip was inconclusive in this region. In the southeastern part of the Temblor Range, Vedder has found contrasting faunal facies and lithofacies in middle and upper Miocene strata on opposite sides of the Recruit Pass fault, suggesting large dislocations due either to movement in a lateral sense or to crustal shortening along this fault.

(See also discussions of San Andreas fault zone in the sections "Regional Geology" and "Geologic Use of Remote-Sensing Data.")

GEOPHYSICAL INVESTIGATIONS

Small earthquakes may provide important clues to the probable occurrence of large damaging earthquakes. They also can provide information about the nature of deformation that is taking place in areas which are now tectonically active.

INSTRUMENTATION

Three types of equipment have been designed to record the data necessary for monitoring and studying these small earthquakes. This equipment includes a portable, remote-recording seismic station which can record seismic data for up to 10 days without attention. The data are recorded on magnetic tape and later may be played back either in the form of a standard seismogram or in special formats needed for detailed studies. Twenty of these seismic stations are now in operation. A second type of equipment consists of a modified seismic-refraction recording system which was formerly used exclusively for recording seismic waves from high-explosive blasts and nuclear explosions. Ten of these systems provide a capability of establishing an array of 8 seismometers that record over a bandwidth of 1–100 cycles per second, and are extremely effective in obtaining detailed information on the location and radiation patterns from very small earthquakes. A third type of system is currently in operation on the island of Hawaii, and an improved design is under development for use along the San Andreas fault in California. This system is a permanent installation providing a network of seismometers that record over an area of 15–30 kilometers in radius with data transmitted to a central recording point.

TOPICAL EARTHQUAKE STUDIES

Yellowstone earthquakes recorded

A research network of short-period seismographs has been established by the U.S. Geological Survey in cooperation with the National Park Service in Yellowstone National Park, Wyo., and adjacent areas of western Montana. During the fall of 1965, the 5 permanent stations of the network were augmented by an equal number of portable low-speed tape-recorder stations for an intensive study of the epicentral region of the 1959 Yellowstone–Hebgen Lake earthquake and its southeastward extension into the park.

A. M. Pitt reports that a practically continuous background of about 10 earthquakes per day was recorded by the permanent stations during 1965. Most of these events had magnitudes between 1 and 2 and originated at depths of only a few kilometers in the epicentral zone of the 1959 earthquake and the adjacent west-central portion of Yellowstone Park. Five discreet swarms of earthquakes emanating from restricted zones in this region over periods of a few hours to a few days were also recorded during the year. Except for their concentration in time and space, the swarms of earthquakes were similar to those forming the random background of events in the region.

A few additional earthquakes were recorded from widely scattered points elsewhere in Yellowstone Park.

Denver-area earthquakes

An extensive study of a series of earthquakes in the vicinity of Derby, a suburb of Denver, Colo., has been carried out by numerous investigators including J. H. Healy, of the U.S. Geological Survey. D. M. Evans [53] has proposed that these earthquakes might be related to the injection of water in a deep disposal well at the Rocky Mountain Arsenal. The microearthquake activity in this region defines a pattern of earthquakes of roughly ellipsoidal shape, about 5 miles long, 2 miles wide, and ½-mile thick approximately centered on the disposal well. According to J. H. Healy and others (r0178) the investigations tend to support the proposed relation between the injection of water in the Rocky Mountain Arsenal well and the occurrence of earthquakes in the Denver area.

Earthquakes at Kilauea Volcano

The extensive studies of earthquakes at Kilauea Volcano on the island of Hawaii are continuing and providing an ever-increasing body of information on the relations of earthquakes to the volcanic processes

[53] D. M. Evans, 1966, Man-made earthquakes in Denver: Geotimes, v. 10, no. 9, p. 11–18.

which are occurring there. A combination of the earthquake data with measurements of tilt and strain provides the information necessary for short-term prediction of volcanic eruptions on this island.

A series of earthquakes occurring at about 30-kilometer depths are of particular interest and are currently under study by J. P. Eaton. These earthquakes have patterns of first motion which indicate an unusual source mechanism. The first-motion patterns are compressional on all stations, and the possibility that these particular earthquakes are intimately related to the mechanism of the release of lava at depth is being investigated.

ENGINEERING GEOLOGY

Earthquake hazards in southeast Alaska communities

Reconnaissance studies by R. W. Lemke and L. A. Yehle, directed principally toward assessing potential earthquake hazards, have been completed for the following 10 coastal towns in southeast Alaska: Haines, Hoonah, Ketchikan, Metlakatla, Mount Edgecumbe, Petersburg, Port Chilkoot, Sitka, Skagway, and Wrangell. The investigators have tentatively concluded that most parts of these towns are built on more stable geologic materials than those beneath towns that were heavily damaged by the 1964 Alaska earthquake. Nevertheless, if a major earthquake occurred in this region, strong ground motion probably would cause heavy damage in some towns where manmade structures are built chiefly on poorly consolidated materials. Parts of some communities might also be affected by slides of rock and snow, ground fissuring, sand boils, and subsidence due to soil compaction. Some towns are susceptible to damage caused by tectonic land-level changes that might accompany an earthquake. In addition, harbor areas and other low-lying parts of some towns could be damaged by seismic sea waves, seiche waves, and waves produced locally by submarine landslides.

Movement now occurring along Hayward fault zone in California

Slow, apparently continuous movement along the Hayward fault zone (D. H. Radbruch, r0115) near San Francisco, Calif., is described by D. H. Radbruch and M. G. Bonilla, of the U.S. Geological Survey, and others (r1853). Manmade structures have been damaged by tectonic "creep" in at least four places within the fault zone along the east side of San Francisco Bay. Movement at each place has been right lateral, that is, the northeast side of the fault has moved southeastward with respect to the southwest side. The amount of movement at different localities ranges from 1.25 inches in 11 years (average rate of 0.11 in/yr) to 8 inches in 55 years (average rate of 0.14 in/yr). The four areas where creep is taking place are near the ends of a 20-mile segment of the Hayward fault zone, and movement may also be occurring in intervening areas within this segment. Persons concerned with the design, construction, or maintenance of structures in the areas of creep should be aware of the probability of damage due to continuous slow movement along an active fault, as well as the possibility of sudden rupture during an earthquake.

NATIONAL CENTER FOR EARTHQUAKE RESEARCH

A National Center for Earthquake Research (NCER) has been established at Menlo Park, Calif., by the U.S. Geological Survey to investigate fundamental problems related to predicting earthquakes. An advisory board, consisting of Dr. Frank Press, of the Massachusetts Institute of Technology, as chairman and with 6 to 8 members, is being organized to guide the Geological Survey in planning and conducting the earthquake-prediction research program.

The National Center for Earthquake Research has several important functions:

(1) To focus the research of the Geological Survey on the problems of earthquake prediction and to investigate the physical basis of earthquakes.

(2) To provide a mechanism for establishing closer cooperation among the Geological Survey, universities, other Government agencies, and industry, for research on earthquake prediction.

(3) To provide an international research center where American and foreign scientists can perform research on earthquake prediction as visiting scientists.

The initial research effort within the National Center for Earthquake Research is being focused on the active earthquake zones of California, Nevada, and Alaska, but other areas such as Montana and Colorado are also included in the program of study.

EFFECTS OF THE 1964 ALASKA EARTHQUAKE

The Alaska earthquake of March 27, 1964 was one of the strongest and most destructive ever to shake the North American continent. As such, it has both deserved and received a major study of all earth-science aspects of its effects. Some field studies were continued through 1966, but the U.S. Geological Survey's main effort was devoted to preparation and publication of a series of professional papers on the results of its investigations. Where needed to complete the record, reports by other organizations or individuals will be included in the series.

Geologic field studies

Detailed maps were made by George Plafker, M. G. Bonilla, and L. R. Mayo of the only two surface faults on land known to have moved during the earthquake. Those faults are 3 and 20 miles long, respectively. Both faults broke along preexisting fractures for much of their length. Surface expression of the faults varied markedly from sharp, clean scarps as much as 16 feet high in bedrock, to broad flexures or zones of en echelon surface cracks in areas mantled by thick alluvial or glacial deposits. The faults are vertical or reverse faults with virtually dip-slip displacement. Reconnaissance studies of the vertical tectonic displacements in coastal areas, which were begun in 1964, were extended by Plafker to remote portions of the Kenai Peninsula, the Kodiak region, the coastal region east of Prince William Sound, and the contiguous islands on the continental shelf.

Gravity data

D. F. Barnes has made more than 50 postquake reoccupations of gravity stations that were established before the Alaska earthquake. Almost all the data strongly suggest that the large changes in land level were accompanied by subsurface rock shifts and could not have been caused by chemical reactions or phase changes. The data also show that the large free-air anomalies which indicate the lack of good isostatic adjustment in southern Alaska were increased by the earthquake. The measurements have indicated the need for better gravity base-station control in earthquake areas, so the Geological Survey is attempting to improve this control in southern Alaska.

Reports on the Alaska earthquake

The first three parts of a volume (U.S. Geol. Survey Prof. Paper 1542) describing the earthquake's effects on communities were published during the year. Civilian and military buildings, utilities, and other installations at Anchorage, Alaska's largest city, were severely damaged by seismic vibration and ground cracks, but more particularly by translatory landslides in sensitive clays. These caused significantly large segments of urban land to slide many feet on nearly horizontal planes (W. R. Hansen, r1529).

Whittier, a small seaport and rail terminal at the head of Passage Canal on Prince William Sound was damaged by subsidence, seismic vibrations, submarine slides, and waves generated by the landslide. Because of local geologic conditions it afforded the best corroboration of all the damaged communities of a well-known geologic principle—buildings founded on bedrock withstand seismic shock better than those built on sand or gravel (Reuben Kachadoorian, r0418).

The port of Valdez was damaged by ground cracks, waves, and a massive submarine slide that demolished the dock facilities so that city officials, on the advice of geologists, decided to move the entire town rather than attempt to rebuild it (H. W. Coulter and R. R. Migliaccio, r0417).

The main part of Homer, a fishing and shipping port on Cook Inlet, was but slightly damaged, but its commercial heart, the Homer Spit, was so affected by tectonic subsidence, compaction of sediments, and a submarine slide that all shipping and related facilities required rebuilding, as reported by R. M. Waller.[54]

The first of several reports on regional effects of the earthquake is one by D. S. McCulloch.[55] Kenai Lake, one of the larger bodies of water on the Kenai Peninsula, was the scene of underwater landslides that generated destructive waves, and of seiche waves, akin to the sloshing of water in a tilted washbasin.

In addition to the volumes on communities and on regional effects, reports are in various stages of preparation on the earthquake's effects on the hydrologic regimen, on transportation, communications, and utilities, and on the history of the field investigations and the gigantic reconstruction effort that began immediately after the earthquake.

Preliminary reports on vertical tectonic displacement, submarine slides, and destructive waves were published by George Plafker[56] and by Plafker and L. R. Mayo (r0118). An area of more than 50,000 square miles was tectonically affected by the earthquake. The northwest part of a great belt that lies between the Aleutian Trench and the Aleutian volcanic arc sank as much as 7.5 feet, whereas the southeast part of the belt, which includes most of Prince William Sound, rose 4–8 feet in most places and locally at least 33 feet. In addition to the long-term effects on living organisms and manmade structures of these sudden changes in sea level, the vertical displacement of the sea bottom generated a train of destructive seismic sea waves, that was propagated throughout much of the Pacific Ocean.

Alaska earthquake motion picture

A motion picture, entitled "The Alaskan Earthquake, 1964," has been released for educational loan use or purchase. In color and sound, it incorporates film taken by Survey scientists just after the earthquake, as well as animated sequences and models, to

[54] R. M. Waller, 1966, Effects of the earthquake of March 27, 1964, at Homer, Alaska: U.S. Geol. Survey Prof. Paper 542–D, 28 p. [published July 1966]

[55] D. S. McCulloch, 1966, Slide-induced waves, seiching, and ground fracturing caused by the earthquake of March 27, 1964, at Kenai Lake, Alaska: U.S. Geol. Survey Prof. Paper 543–A, 41 p. [published July 1966]

[56] George Plafker, 1965, Tectonic deformation associated with the 1964 Alaska earthquake: Science, v. 148, no. 3678, p. 1675–1687.

illustrate the geologic conditions that produced seismic vibrations, landslides, and sea waves. A set of 75 annotated color slides showing geologic effects and damage caused by the earthquake was also placed on file for public inspection and purchase.

Committee on the Alaska earthquake

The U.S. Geological Survey also continued active participation in the work of the Committee on the Alaska Earthquake, National Academy of Sciences. This committee is charged with preparation of a comprehensive report on all scientific and engineering aspects of the earthquake. Inasmuch as the earthquake was a geologic event, findings of earth scientists are necessarily basic to the work of nearly all the Committee's panels.

GEOPHYSICAL INVESTIGATIONS

STUDIES OF THE CRUST AND UPPER MANTLE

REGIONAL SEISMIC-REFRACTION STUDIES

Reconnaissance studies of the structure and properties of the earth's crust and upper mantle in the United States were filled out during the past year by a series of seismic-refraction measurements that completed an almost-continuous chain of profiles across the continent from California to South Carolina. New links in this chain included profiles that were designed to investigate the transition from the Rocky Mountains to the Great Plains, profiles across the Appalachian Mountains from the Cumberland Plateau, in Tennessee, to the Atlantic coast near Charleston, S.C., and a large number of recordings of seismic waves from explosions fired offshore along lines extending from the coastline across the continental shelf during the East Coast Onshore-Offshore Seismic Experiment.

Appalachian Highlands crust thicker than that of Atlantic Coastal Plain

J. C. Roller reports that a preliminary examination of data collected in an extensive seismic-refraction program between the Cumberland Plateau and the Atlantic coast indicates that the crust is predominantly "granitic" and about 30 kilometers thick beneath the Atlantic Coastal Plain, and that it is predominantly "basaltic" and about 45 km thick beneath the Appalachian Highlands.

Rocky Mountain crust differs little from that of Great Plains

Analysis of seismic data recorded in the Rocky Mountains indicates a total crustal thickness of 54 kilometers, practically the same figure as that found for the High Plains of Colorado and New Mexico, according to J. C. Roller. Isostatic equilibrium between these two provinces is not maintained by a difference in crustal structure, but by a difference in upper-mantle density.

Low attenuation of seismic waves noted in upper mantle beneath the midcontinent

During the past year, traveltimes and amplitudes of longitudinal seismic waves generated by explosions in Lake Superior and recorded along a profile extending to Denver, Colo., were defined. J. C. Roller and J. H. Healy report that measurements at intervals of 30 kilometers along this profile showed P-wave amplitudes decreasing approximately as the reciprocal of the distance. Similar measurements in the Basin and Range province from the SHOAL nuclear explosion show a decrease of amplitude with distance proportional to the reciprocal of the cube of the distance.

The P-wave velocity recorded on the profile from Lake Superior to Denver was 8.1 km/sec from 275 to 800 km; and it was 8.5 km/sec from 800 km to about 2,500 km along an extension of the profile to Payson, Ariz. The 8.5-km/sec portion of the curve can be attributed to a zone with that velocity in the upper mantle at a depth of about 100 km.

Thus, both velocity and amplitude data indicate that the upper mantle beneath the midcontinent region must differ significantly from that beneath the Western United States.

Cooperative seismic experiment in Norway

One long refraction profile in a north-south direction in Norway and two shorter profiles crossing southern Norway were completed in September 1965. J. H. Healy reports that data from these profiles, being analyzed in cooperation with the University of Bergen, should provide a reconnaissance definition of crustal structure and of the properties of the upper mantle in Norway.

Intermediate rocks a major constituent of Sierra Nevada crust

According to an analysis by J. P. Eaton of a longitudinal seismic-refraction profile in the Sierra Nevada, the high southern part of the range is underlain by a crust about 54 kilometers thick. The crust thins beneath the northern end of the range and undergoes drastic changes in character at the Sierra Nevada–Cascade Range boundary.

The velocity of P waves beneath the Sierra Nevada is 7.9 km/sec in the upper mantle and 6.0 km/sec in the upper part of the crystalline crust. Rocks with intermediate P-wave velocities (6.4 to 6.9 km/sec) form a major part of the Sierra Nevada root in the central part of the range, where the root extends to about twice the depth of the base of the crust in the adjoining regions to the northeast and southwest.

REGIONAL GRAVITY STUDIES

Gravity survey in southwestern Oregon

A reconnaissance gravity survey of a 75×130-mile area of southwestern Oregon, to investigate major crustal elements in a transition zone from a continental to an oceanic environment, was completed by H. R. Blank, Jr. (p. C113–C119). A contoured Bouguer anomaly map of this region shows an average west-to-east negative gradient that corresponds qualitatively to an inland thickening of the continental crust. Gravity highs in the Coast Range may reflect ultramafic bodies at depth, as well as near-surface accumulations of lower Eocene basalt. Anomalous northeast trends in the Cascade Range are attributed to a concealed extension of the Klamath Mountains upwarp. A negative anomaly not exceeding 10 milligals is associated with Crater Lake caldera, and a negative anomaly of 20 to 30 mgals coincides with the northern end of the Klamath graben.

Regional gravity anomaly from topography

Local gravity anomalies cannot be analyzed properly until the regional anomaly is removed from the simple Bouguer anomaly. One method commonly used is to compute the Pratt-Hayford isostatic correction to the simple Bouguer anomaly, but D. R. Mabey (p. B108–B110) has found that it is much quicker and easier to determine the regional anomaly from a linear relation with average elevation. A correlation was found between topography and Bouguer anomalies in Nevada by calculating the average elevation within 64 kilometers of each gravity station and comparing it with the Bouguer anomaly there. A similar relationship was determined for the eastern Snake River Plain in Idaho. The regional anomaly in Nevada is found by multiplying the average elevation by a factor of −0.032 milligal per foot with a zero elevation correction of +3 mgal. The average elevation for each station is normally computed to apply a topographic correction anyhow in gravity studies, so only one more calculation is needed to determine the regional anomaly at the station. However, the relation found between elevation and anomaly is valid only within a local physiographic region; so the same relation cannot be applied to all areas. For example, in the Snake River Plain, Mabey determined the elevation-anomaly factor to be −0.034 mgal per foot with a zero correction of +35 mgal. Variation in this relation from region to region is also demonstrated by the great scatter of plots of elevation versus Bouguer anomaly for data from extended areas.

Upper-mantle properties maintain isostatic balance of large topographic features

Attempts to reconcile observed values of gravity with those deduced from models of crustal structure determined from seismic-refraction measurements have shown that variations in the properties of the upper mantle must play an important role in maintaining the isostatic balance of large topographic features. In an increasing number of areas, such as one in southern Mississippi investigated by David Warren and J. H. Healy, features no larger than 50 kilometers across appear to be associated with anomalies in density of the upper mantle. Comparisons of seismic-refraction and gravity observations require a marked change in the properties of the upper mantle between the Rocky Mountains and the Great Plains.

Errors in instrument calibration limit precision of gravity surveys

To check the calibration of several types of commercial gravity meters used by the U.S. Geological Survey, H. W. Oliver has analyzed the data from more than 40 runs on the Mount Hamilton calibration loop made with La Coste, Worden, World-Wide, and North American gravity meters between 1961 and the present. The loop includes 5 intermediate points between bases at Menlo Park, Calif., and the top of Mount Hamilton and has a toal gravity relief of 309.32±.03 milligals. The plus-or-minus value refers to the standard deviation of data obtained with La Coste meter G–17B, which has been indirectly calibrated against Woollard's North American standardization range; the 95-percent confidence limits are ±0.02 mgal. A comparison of differences between this and intermediate points with those obtained by other meters indicates that (1) the factory calibration of Worden meters used by the Geological Survey is consistently too high by about 1 part in 600 (this calibration error introduces an observed-gravity error of about 2½ mgal in the Sierra Nevada, where differences as large as 1,500 mgals are observed), (2) the factory calibration of the World-Wide meter used by the Survey is not sufficiently accurate for regional work, although usable for local studies; and (3) the factory calibrations of the La Coste meters used by the Survey are inconsistent generally by a few parts in 10,000, an inconsistency which is significant relative to the 1-part-per-10,000 reproducibility of the instrument.

GEOTHERMAL STUDIES

New heat-flow measurements from central California

A. H. Lachenbruch reports a preliminary heat-flow value from the central Sierra Nevada of 1.3 microcalories/cm²/sec. Although the seismic root of the range extends to a depth of more than 50 kilometers, a slab of the local rock only 15 km thick could generate this flux. The strong upward concentration of U, Th, and K indicated by this result might be explained by fractionation in geosynclinal sediments during magma generation. Subsequent erosion of source-enriched surface rocks could reduce the steady heat flow substantially. At the eastern margin of the San Joaquin Valley the preliminary value of the heat flow is only 0.62 μcal/cm²/sec. The difference in the two heat flows is equivalent to that produced in an 8-km slab of the rocks of the central Sierra Nevada. The vertical redistribution of crustal sources suggested by these preliminary measurements could have substantial effects on temperatures of the lower crust and upper mantle, and on magma generation.

Sharp discontinuity in thermal properties of crust beneath Arctic Ocean

The decrease in heat flow from 1.4 microcalories/cm²/sec in the northern Canada Basin to 0.8 μcal/cm²/sec on the southern flank of the Alpha Rise in a horizontal distance of 25 kilometers is best explained by a sharp discontinuity in thermal properties involving the entire crust, according to A. H. Lachenbruch and B. V. Marshall (r1903). Existing theories on the origin of the Alpha Rise imply upward movement of the rise relative to the basin. The thermal interpretation requires high conductivity on the basin side; and this implies that if relative movement occurred it was in a sense opposite to that required by present theories.

Equilibrium geothermal gradients unchanged in flooding of drillhole

In connection with a routine determination of terrestrial heat flow near Morgantown, W. Va., two unusual observations were reported by W. H. Diment: (1) When the dry hole was filled with water the temperatures returned to the pre-injection values after the injection transient had dissipated, thus providing experimental verification that the contents of a borehole have little influence on equilibrium geothermal gradients, (2) After this large-diameter hole (26 cm) was filled with water and the resulting temperature disturbance subsided, the temperatures at each depth were observed to oscillate several hundredths of a degree. The amplitude of the oscillation was roughly proportional to the temperature gradient at the point of observation, and the dominant periods were on the order of several minutes.

Source of heat for Steamboat Springs, Nev., suggested

D. E. White [57] has calculated the heat flow from the immediate area of Steamboat Springs, Nev., to be about 12×10^6 calories per second. It is contained in an upflow of 70 liters/second of water at a temperature of 170°C (prior to near-surface boiling). This convective heat flow is from an area of about 5 square kilometers and is equivalent to the conducted heat flow of 780 km² of "normal" flow. The surrounding area, moreover, also has abnormally high heat flow. The Steamboat Springs anomaly is equivalent to the heat obtainable from the cooling and crystallization of about 0.001 cubic kilometers of granitic magma per year. In view of the age of the system—100,000 to 1 million years—a magma supply of 100 to 1,000 km³ is required. A convecting magma chamber with deep roots constitutes the most satisfactory model for supplying such high heat flow for a long time, but this possibility has not yet been confirmed experimentally by other field evidence.

Determination of heat flow in boreholes at Savannah River Plant

The deep boreholes in the metamorphic rocks at the Savannah River Plant, S.C., presented an unusual opportunity for determining the flow of earth heat. W. H. Diment, of the University of Rochester, I. W. Marine and G. E. Siple, of the U.S. Geological Survey, and James Neiheisel, of the U.S. Corps of Engineers (Diment and others, r1508), report that in the metamorphic rocks the mean geothermal gradient is about 15°C per kilometer, the mean thermal conductivity is about 6.7 millicalories per centimeter per second per degree Centigrade, and the heat flow is 1.0±0.1 microcalories per square centimeter per second. The temperature gradient in the metamorphic rock was about the same several days after drilling as it was more than a year later. This finding indicates that, under some circumstances at least, gradients useful in the computation of heat flow can be obtained shortly after drilling. Temperature gradients in the sediments that overlie the metamorphic rocks seem to be related to lithology. Thermal-conductivity values for the porous sediments seem to be slightly high; this observation suggests that the thermal regime in the sediments is influenced by the movement of ground water.

[57] D. E. White, in press, Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U.S. Geol. Survey Prof. Paper 458-C.

THEORETICAL AND EXPERIMENTAL GEOPHYSICS

ROCK MAGNETISM

Geomagnetic chronology

Some revisions have been made by R. R. Doell, Allan Cox, G. B. Dalrymple, and C. S. Gromme in the chronology of geomagnetic polarity. The revised diagrammatic time scale is given in the table below. The most important of these revisions are the changes in the Brunhes-Matuyama boundary from 0.85±0.15 to 0.7±0.05 million years and the discovery of the new normal Jaramillo event at about 0.9 m.y. within the Matuyama reversed epoch. The Jaramillo event is based on studies of volcanic rocks from Valles caldera, N. Mex.; this event is represented by one unit of rock with normal polarity and another unit with an intermediate direction of magnetization. Additional results on volcanic rocks from New Mexico, the Sierra Nevada (California), and the Pribilof Islands (off the coast of Alaska) have substantiated the chronology as shown in the table for the 0–4 million-year interval, and it seems unlikely that important revisions will be made to this time scale.

Reversed geomagnetic polarity	Age (m.y.)	Normal geomagnetic polarity
	0. 0	
		Brunhes epoch
	0. 7±0. 05	
Matuyama epoch	(0. 85–0. 95)	(Jaramillo event)
	(1. 8–1. 9)	(Olduvai event)
	2. 4±0. 1	
(Mammoth event)	(3. 0–3. 1)	Gauss epoch
	3–35±0. 1	
Gilbert epoch		

Polar wandering, continental drift, and the onset of Quaternary glaciation

Polar wandering has been linked to the onset of glaciation by several theories which suggest that glaciation began as the earth's rotation axis migrated toward potential regions of glaciation, such as Antarctica or the Arctic Ocean. Allan Cox and others (r1799) have concluded that these theories are not in agreement with paleomagnetic evidence because although the maximum estimate for the duration of the Quaternary is about 3 million years, the paleomagnetic evidence indicates that the rotation axis has been within the present polar region for at least 20 million years.

Cox also points out that current estimates of the rate of continental drift are far too small for changes in the configuration of continents to have played an important role in the onset of Quaternary glaciation. He concludes that the possibility remains that vertical movements of land masses, many of which occurred at the end of the Pliocene, may have played a significant role in the initiation of Quaternary glaciation.

Magnetic properties of rocks and minerals

C. A. Kaye, in cooperation with J. De Boer, of Wesleyan University, has investigated the magnetic properties of diabase dikes in the Boston, Mass., area. The paleomagnetism of 15 samples taken from the highly magnetic dikes of Permian age (K-Ar determination) indicated that 9 of these have been influenced by lightning effects. The TRM (thermoremanent magnetization) of the other 6 is directed toward a pole located at approximately 100° E. 32° N., which pole falls within the cluster of Permian and Carboniferous poles obtained in the Western United States. The intensity of magnetization varies greatly from 5×10^{-2} to 2×10^{-3} electromagnetic units per cubic centimeter. The most magnetic of the influenced samples have intensities up to 1 emu/cm^3, which is very high for a presumably normal mafic rock. Demagnetization up to 800 oersteds hardly decreased this intensity (only a factor of 100), and so the samples must have been remagnetized in fields higher than this. By looking at the distribution of the intensities, a more or less northeast-southwest linear path (about 12 feet long) could be established. The mixed-up directions of TRM indicate that the dike may have been hit several times.

Investigations of six differentiated Triassic diabase sheets in Pennsylvania by M. E. Beck, Jr. (p. D109–D116), show that a marked increase occurs in remanent and induced magnetic intensity with crystal fractionation. He concludes that this increase in magnetic moment probably reflects absolute enrichment in total iron, accompanied by a rise in the relative importance of ferric iron, in passing from mafic to felsic differentiates. Especially high stability of remanent magnetization seems to be associated with the mafic fraction.

PHYSICAL PROPERTIES OF ROCKS

Measurement of elastic moduli of rock in tunnels

Observations were made by R. D. Carroll, J. H. Scott, and D. R. Cunningham (p. C25–C28) of the velocity of compressional and shear waves in granite in the Straight

Creek Tunnel in Colorado and in the Climax stock at the Nevada Test Site, Nevada. Using these data and knowing the density of the rocks, they calculated the rigidity, Young's modulus, bulk modulus, and Poisson's ratio. The underground technique utilized sensitive accelerometers placed in drill holes, electronic amplifiers, and an oscilloscope. Seismic waves were produced by detonating a blasting cap in a shallow shot hole 30 to 100 feet from the geophones. The wave train displayed on the oscilloscope was photographed, and P and S waves were identified. Consistent results were obtained for the two granites, and average values were found to be: Young's modulus, 8×10^6 pounds per square inch, shear modulus, 3×10^6 psi, bulk modulus, 8×10^6 psi, and Poisson's ratio, 0.33.

Shock-wave velocities by a new method

The physical properties of rock under very high pressures can be obtained from shock waves induced by explosives. It is necessary to measure the particle velocity and the shock-wave velocity, but the usual inclined-mirror techniques require elaborate preparation. A new method to measure shock velocity was developed by M. H. Carr (p. B99–B103); it utilizes two electrical-resistance, SR–4 strain gages to measure times of arrival of the shock wave at two points along a rock sample. The shock-wave velocity in the rock is determined from the distance between the gages (1 cm) and the wave traveltime. Response time of the SR–4 gages is 0.04 microsecond, which is adequate for velocities to 7 kilometers per second. An aluminum specimen with two SR–4 gages is placed ahead of the rock specimen to determine the particle velocity; the relation between shock-wave velocity and particle velocity is well known in the aluminum. A voltage is impressed across each pair of SR–4 gages, and the traveltimes for the aluminum and rock specimens are obtained from simultaneous display on a dual-trace oscilloscope.

For many rocks and at pressures below 80 kilobars, the SR–4 strain gages are not usable because the shock-wave signal is obscured by a precursing elastic-wave signal. The gages can be used in rocks like the Coconino Sandstone and in metals, in which the elastic wave is overdriven by the shock wave. The density of Coconino Sandstone was increased 56 percent under a pressure of 134 kb, and its shock-wave velocity increased from about 3.0 to 3.9 km per sec for this pressure increase. Similar results were observed in sandstone from the Moenkopi Formation, Yule marble, and basalt specimens.

Relationship between electrical conductivity and dielectric constant

The conductivity and the dielectric constant are the controlling electrical properties for propagation of electromagnetic energy through rocks and soil. Although it is possible to measure directly the conductivity of rock in place at low frequencies, there is no satisfactory method for measuring the dielectric constant of rock in place. Laboratory measurements by J. H. Scott of the conductivity and dielectric constants of rock and soil samples have been statistically correlated over the frequency range of 10^2 to 10^6 cycles per second as a function of low-frequency conductivity and moisture content. These correlations allow for estimating the dielectric constant in situ as either a function of low-frequency conductivity or water content, both of which can be measured easily in the field.

Errors in porosity determinations

The values for bulk volume, grain volume, and indirectly the pore volume depend on the method of measurement. In fact, at low porosities the difference in bulk volume, varying according to the method of measurement, can be greater than the porosity itself. An evaluation of the methods of volume measurement was made by G. E. Manger (r1907).

SOLID-STATE STUDIES

Elastic and anelastic properties of solids

Previous methods of calculating the average elastic constants of single crystal aggregates invoked unrealistic assumptions regarding the stress (or strain) distribution in the aggregate. These assumptions led to dissimilar values for the calculated averages, especially when the anisotropy of the single crystal was large. A variational method for calculating the average elastic constants, based on an energy extremum, and not using the assumptions on stress or strain has been extended by Louis Peselnick and Robert Meister to aggregates having tetragonal single crystals. The bounds of the effective moduli obtained in this way show a considerable improvement over the bounds found from employing the conventional stress-strain assumptions.

A. F. Hoyte has determined the elastic constants of $CaMoO_4$. The crystal is tetragonal in symmetry belonging to the class 4/m. This class of crystals has seven elastic constants, C_{11}, C_{33}, C_{44}, C_{66}, C_{12}, C_{13}, and C_{16}. A system of velocity measurements was made, and equations were set up to give a unique determination of the constants. A direct analytic solution to the set of equations obtained from the measurements is not obvious, hence the method of iteration is being tried. The constants directly determined and their values are as follows:

$$C_{33}=12.138\times10^{11}\ \text{dynes/cm}^2$$

$$C_{44}=3.525\times10^{11}\ \text{dynes/cm}^2$$

Thermodynamic properties of minerals

R. A. Robie has measured the heat of solution of dolomite in 4.360 molal HCl at 30°C. The Debye temperature of 14 crystals principally of low symmetry was obtained by numerical integration over the sound-velocity surfaces calculated from the single-crystal elastic constants. It was shown that an earlier calculation using similar numerical techniques is in error for crystals of trigonal symmetry.

Magnetic properties of minerals

R. R. Lewis and F. E. Senftle have shown that the source of weak ferromagnetism in granitic zircons reported previously (U.S. Geol. Survey, r1929, p. A146–A147) is due to ferromagnetic iron oxides on the grain surfaces. A similar effect has been observed by Sherman White in tourmaline. A. N. Thorpe and Senftle have investigated the magnetic properties of tourmaline to very low temperatures (8°K) and found antiferromagnetism in some but not all specimens. Further structural studies are in progress with G. Donnay, Johns Hopkins University, to determine the cause of the antiferromagnetism.

As a continuing study of the magnetic properties of TiO_2 the magnetic susceptibility of the orthorhombic form, brookite, has been measured by Thorpe and Senftle from room temperature to 5° K. After correction for the temperature-dependent component due to a small amount of impurity, the value of the susceptibility of the three forms was found to be

Mineral	*Form*	*Susceptibility (emu/g)*
Anatase	Tetragonal	0.040×10^{-6}
Anatase	Tetragonal	$.067\times10^{-6}$
Brookite	Orthorhombic	$.11\times10^{-6}$

After correction for the basic diamagnetism, there is a residual paramagnetism which can be ascribed to the distortion of the TiO_6 octahderon in TiO_2. The degree of distortion determined from Ti–O bond lengths in the three forms of TiO_2 is in the same order as the temperature-independent paramagnetism.

Thorpe, White, and Senftle have determined the magnetic susceptibility of tourmaline down to 8°K. Buergerite is magnetically anisotropic and antiferromagnetic at low temperatures. Donnayite is also antiferromagnetic, but is isotropic.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

FIELD STUDIES IN PETROLOGY AND GEOCHEMISTRY

Mechanism of origin of batholiths

In a survey of features of batholiths in the United States, Warren Hamilton and W. B. Myers conclude that batholiths generally are thin, having spread out laterally at shallow depth, and that many of them reached the surface and crystallized beneath a cover of their own volcanic ejecta. Hamilton and Myers infer that the magmas rose through the crust from sources in the lower crust or upper mantle at depths greater than any ever exposed by erosion. Such conclusions agree with those reached by many geologists, but disagree with the concepts that batholiths are masses of great thickness, form beneath a deep cover of metamorphic rocks, and crystallize from melts mobilized at the levels exposed in gneissic and migmatitic terranes.

Regional uranium and thorium enrichment in Colorado Front Range

George Phair reports that precise uranium and thorium analyses of 203 samples from the Roberts and Adams tunnels in the Front Range of Colorado confirm a regional enrichment of these elements. The tunnels aggregate 34 miles in length, and penetrate varied crystalline lithologies. The average Th and U values are in excellent agreement with published averages of surface samples.[58]

	Surface outcrops	*Roberts Tunnel*	*Adams Tunnel*
$Th_{(av)}$	22.7 ppm	22.4 ppm	24.5 ppm
$U_{(av)}$	4.6	5.9	5.2

This enrichment of radioactive elements may provide a partial explanation for the recurrent magmatism in the region.

Possible reversal of conventional-texture-volatile-content relationship in granite

As a result of studies of rocks belonging to the Pikes Peak Granite magma series in and near the Lake George beryllium area Colorado (C. C. Hawley and others, p. C138–C147), C. C. Hawley has suggested that the finer grained members of some granitic suites may have crystallized from melts containing higher concentrations of volatile constituents than those from which coarser grained members of the same suite crystallized, which is the reverse of the usually

[58] George Phair and David Gottfried, 1964, The Colorado Front Range, Colorado, U.S.A., as a uranium and thorium province, *in* J. A. S. Adams, and W. M. Lowder, eds., The natural radiation environment: Chicago, Univ. Chicago Press, p. 7–38.

accepted relationship. Hawley reasons that the net effect of an increasing volatile content on viscosity (which is important in determining grain size) is the resultant of two opposing tendencies: one to decrease viscosity by breaking Si-O bonds, and the other to increase viscosity by lowering solidus temperatures. He proposes that in some cases the latter tendency overrides the former, and that very volatile-rich melts crystallize to fine-grained crystalline aggregates. As evidence that this relationship is valid in the Lake George area rocks, Hawley points out that seven granitic units that can be distinguished in the closely related Pikes Peak and Redskin Granites form a series in which grain size decreases with decreasing age and apparent increase in volatile content as indicated by small but consistent trends in chemical and mineralogical composition and texture.

This hypothesis may have some economic significance; if it is correct it means that some fine-grained granite masses—which often have associated ores—did not form from volatile-poor magmas but from volatile-rich ones and that the volatile content could very well have been the somewhat younger ore-forming fluids.

Clinopyroxenes from igneous rocks, Little Belt Mountains, Mont.

I. J. Witkind reports that optical, X-ray diffraction, and chemical study of clinopyroxenes separated from 10 igneous rock bodies exposed along the north flank of the Little Belt Mountains, Mont., have revealed a surprising uniformity of physical and chemical properties. Pyroxenes from rocks ranging from plagioclase shonkinite to quartz monzonite are nearly identical in optics, diffraction patterns, and relative proportions of Ca, Mg, and Fe. Variation in Al content is much greater but the number of samples is insufficient to establish any systematic trend in this parameter.

Carbonatite veins in northern Wet Mountains, Colo.

M. H. Staatz and N. M. Conklin report (p. B130–B134) that carbonate veins of the Road Gulch area in the northern Wet Mountains that contain monazite, bastnaesite, thorite, and fergusonite should be classed as carbonatites. Carbonatites are commonly in or related to alkalic igneous rocks, and these veins lie only 1.4 miles west of the large alkalic intrusive complex at McClure Mountain, about 13 miles north of Westcliffe, Colo.

Proposed nomenclature of layered intrusions helps reveal similarities

E. D. Jackson has suggested that many of the similarities between the Stillwater, Great Dyke, and Bushveld complexes have been unrecognized because of differences in terminology among different workers. He has proposed a uniform nomenclature to describe rocks formed by crystal accumulation that includes terms for rock components, rock names, kinds of horizons, kinds of layers, and groups of layers. Comparison of the rocks of the ultramafic zones of the three intrusions in terms of such a standard nomenclature emphasizes their similarities in mineralogy, texture, mineral associations, internal structure, and stratigraphy. Small differences in kinds, proportions, and compositions of settled minerals suggest slight differences among their primary basaltic magmas. Differences in some mineral associations between the Bushveld Ultramafic zone and the ultramafic zones of the other two complexes indicate minor differences in crystallization paths during fractionation. The predominant kinds of layering and the kinds of contacts between the layers of these three intrusions are different from those of the Skaargaard and Rhum intrusions, and require a different explanation.

"Peridotite" xenoliths in Hawaiian basalt

E. D. Jackson reports (D151–D157) that xenoliths consisting of clinopyroxene-garnet-olivine and olivine-orthopyroxene-clinopyroxene, as well as xenoliths gradational between these types, are found in Hawaiian volcanic rocks. As a field classification he refers to all such xenoliths as "peridotites." Garnet-bearing xenoliths have now been recognized in the Aliamanu and Makalapa Tuffs; their previously known occurrence being in the Salt Lake Tuff of Oahu. These garnetiferous xenoliths however are not chemically equivalent, generally, to Hawaiian basalt. The garnet-free xenoliths show a close relationship chemically to their host basalts, a feature recognized earlier by R. W. White.

Rate of palagonitization of submarine basalt

Study of lava samples collected from submarine slopes of three Hawaiian volcanoes and from a sublake flow in Japan indicate to J. G. Moore (p. D163–D171) that palagonite on these samples formed at a slow and definite rate, although palagonitization of submarine basaltic glass proceeds more rapidly than that in fresh water. The thickness of palagonite as a function of time (T) may be defined as $S=\sqrt{CT}$, where S is thickness and C is a constant.

Constant-volume nature of the serpentinization process

T. P. Thayer reports chemical analyses of fresh and serpentinized ultramafic rocks showing that serpentinization was metasomatic and proceeded at virtually constant volume. Whether the original rock was rich in olivine or pyroxene, the final product of serpentinization is virtually a mixture of serpentine minerals and magnetite; most of the brucite in these rocks is probably a transient, metastable phase. Although serpentinization of either olivine or pyroxene at constant volume requires removal of 40 percent of the original material, relations of serpentine and serpentinite to materials unaffected by the alteration show that no volume changes can have occurred. Widespread association of rodingite with serpentinite is interpreted as evidence that hydrous calcium-aluminum and calcium silicates rather than magnesian chlorites are stable under the conditions accompanying most serpentinization.

Late-stage sodic alteration of mica peridotite, Elliott County, Ky.

Recent X-ray and petrographic analysis by Janice Jolly of an alkalic mica peridotite from Elliott County, Ky., has shown that a late-stage sodic uralitization has occurred in places. The sodic amphibole varieties identified are arfvedsonite, glaucophane, richterite, and kataphorite, which occur in the groundmass and as alteration borders around enstatite and bronzite phenocrysts. Orthopyroxene once formed more than 10 percent of the rock, and in places shows lamellar exsolution intergrowths of enstatite and diopside as well as amphibole borders. Pyroxene and amphibole also form as overgrowths on olivine. X-ray analysis also indicates that much of the dark opaque magnetic material is pyrrhotite and pentlandite.

Alkalic peridotite association in tholeiite sequence

Reconnaissance geologic mapping by J. M. Hoare and W. H. Condon on Nunivak Island, Alaska, together with paleomagnetic data, reveals that highly alkalic mafic magmas containing abundant peridotite inclusions were erupted at 2, or possibly 3, times. The alkalic rocks overlie and underlie large tholeiite flows which form most of the island and apparently contain no peridotite inclusions. Repeated eruptions of peridotite-bearing alkalic rocks interspersed with tholeiitic eruptions are apparently not described elsewhere. Restriction of the peridotite inclusions to the alkalic rocks is interpreted as supporting a cognate hypothesis for their origin.

Eruption of the Bandelier Tuff from a zoned magma chamber

R. L. Smith, R. A. Bailey, and K. O. Dickson have shown that the rhyolitic Bandelier Tuff of New Mexico exhibits striking vertical mineralogical and chemical variation that reflects initial chemical and physical gradients within the magma chamber prior to eruption. X-ray studies and chemical analyses show that as eruption proceeded, alkali feldspar phenocrysts changed from Or_{45} (sodic sanidine) to Or_{20} (anorthoclase), fayalite gave way to hypersthene, and modal quartz decreased. This continuing study shows promise of shedding light on the processes and mechanism of differentiation in silica magma chambers.

Pyroclastic rocks in the Ritter Range pendant, Sierra Nevada

R. S. Fiske reports that more than 95 percent of the lower 8,000 feet of metamorphosed strata in the Ritter Range pendant, of the Sierra Nevada of central California, consists of pyroclastic rocks; about 5 percent of the section consists of lava flows. Collectively, features such as uniform stratification, graded bedding, slump structures, and limestone interbeds indicate that much of the section was deposited beneath the sea. On the other hand, scattered beds rich in accretionary lapilli suggest that at least part of the pyroclastic material was erupted from subaerial volcanoes, and deposits that appear to be welded tuffs indicate some subaerial deposition. Very rapid deposition is indicated by the presence of many thick beds of pyroclastic debris (each deposited virtually instantaneously) and the absence of erosional unconformities and soil zones.

Rhyolitic tuff of high chlorine content in Utah

D. R. Shawe reports that a water-laid rhyolitic tuff near the Roadside beryllium deposit at Spor Mountain, Utah, is anomalously rich in Cl (0.79 and 3.55 percent in two samples). This high Cl content may be due to deposition of chloride salts either from saline solutions that may have formed the beryllium deposits, or from saline waters of Lake Bonneville which covered these rocks during the Pleistocene.

Rock-forming temperatures in Minas Gerais, Brazil

Petrologic studies of metamorphic and igneous rocks associated with the iron formations in the Quadrilatero Ferrifero by Norman Herz in association with C. V. Dutra of the Brazilian Institute of Industrial Technology have provided further information about the conditions under which these rocks were formed. Determination of Co, Ni, Cr, Sc, and Nb in biotite from granite and gneiss showed that Co, Ni, and Cr could potentially be used as geological thermometers as well as Sc. Abundant Nb indicated the onset of a pneumatolytic stage. Determination of alkali feldspars in similar rocks showed temperatures of formation ranging from 280°C in gneiss to 610°C in postmetamorphic granite. Ba and Rb ratios were found to offer valid criteria for differentiating the samples genetically.

Adirondack mineral deposits derived by metamorphic processes

Extensive field and mineralogic study by A. E. J. Engel and C. G. Engel has shown that metamorphism of the Grenville Series in the northwest Adirondack Mountains, N.Y., involves progressive dehydration, decarbonation, and loss of alkalis, silica, and cogenetic trace elements. The volume of Mn, Fe, Ti, Pb, and Zn mobilized from the Grenville sedimentary column exceeds the volume of these elements concentrated in the known economic mineral deposits of the northwest Adirondacks. Most of these deposits appear to be derived in large part by the metamorphic mobilization of the elements from the enveloping subjacent country rock.

Granitic and mafic metasomatism of the Grenville Series

A. E. J. Engel and C. G. Engel have demonstrated the importance of metasomatic processes in the evolution of the Grenville metasedimentary sequence in the northwest Adirondack Mountains, N.Y. Most layered amphibolites, thought by earlier investigators to be derived either from basaltic sills or tuffs, appear to be formed by amphibolitization of original quartzite, limestone, graywacke, and pelite. Phacoliths within the Grenville Series display stratigraphic patterns interpreted as relic bedding, and appear to be the products of large-scale granitization of a basal calcareous quartzite of the Grenville series.

Alteration in Slick Rock district, Colorado

According to D. R. Shawe, unaltered reddish-brown Mesozoic sedimentary rocks of all types in the Slick Rock district, Colorado, are characterized by black opaque detrital grains, films of hematite on other detrital minerals, and hematite dust dispersed in matrix material. Generally, equivalent altered rocks are light colored and contain virtually no hematite, but carry pyrite, marcasite, or limonite oxidized from these sulfides. The altered rocks contain authigenic barite, anatase, albite, and analcite, in addition to the iron sulfides. Calcite has recrystallized, and has developed polysynthetic twins and shears parallel to bedding. These features suggest that alteration occurred after deep burial but prior to folding.

Portable core drill and thin-section laboratory for field use

G. B. Dalrymple and R. R. Doell (p. B182–B185) have developed portable equipment for the preparation and analysis of thin sections in the field. Any desired near-surface part of an outcrop is sampled by a core drill cooled by water carried in a pressurized tank on a backpack. The drill, tank, and sufficient water to drill 50 cores 1½ inches long weigh a total of only 50 pounds. Equipment for making thin sections from the core weighs only 25 lbs, and consists of an 8-inch diamond saw lubricated and cooled by water, a hotplate heated by a single-burner camp stove, and a glass plate for final hand grinding. The thin sections are covered with oil and are inspected on the outcrop with an inexpensive microscope modified for cross-polarized light. Illumination is provided by a 6-volt flashlight. Weight of equipment used in thin section inspection is only 6 lbs.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

Polymorphism in prehnite

The average structure of a prehnite crystal from Tyrol, Austria ($a=4.646\pm0.002$ A, $b=5.483\pm0.002$ A, $c=18.486\pm0.005$ A, Z=2), has been refined in space group *Pncm* by J. J. Papike. This refinement verifies the general features of the model proposed by Peng and others [59] and shows further that the 2 tetrahedral aluminum atoms are restricted to 1 of 2 4-fold tetrahedral positions in the structure. Weak reflections violating both the *n* and *c* glide requirements were observed for the Tyrol material and for prehnites from several other localities. These reflections are interpreted as indicating further fractionation of the two tetrahedral aluminum atoms in the position which has multiplicity four in space group *Pncm*. This fractionation may take place in 1 of 2 ways with both ordering schemes leading to a reduction of the space-group symmetry. One scheme results in a *P*2*cm* space group and the other in a *P*2/*n* space group. Prehnites from several localities appear to be comprised of both orthorhombic and monoclinic domains.

Studies on alkali feldspars

The X-ray methods developed by D. B. Stewart, T. L. Wright, and Dora von Limbach and reported earlier [60] (U.S. Geol. Survey, r1929, p. A153) have been used to refine unit-cell parameters of feldspars from powder-diffraction data. They have studied possible additional applications of these methods using alkali-exchanged natural and synthetic feldspars. When a potassic feldspar and a sodic feldspar of apparently equivalent structural states (as judged by their axial dimensions) are each exchanged with the

[59] Peng Sze-Tzung, Chou Kung-Du, and Tang You-Chi, 1959, The structure of prehnite: Acata Chim. Sinica, v. 25, p. 56–63 [In Chinese].

[60] T. L. Wright, 1964, X-ray determination of composition and structural state of alkali feldspar [abs.]: Am. Geophys. Union Trans., v. 45, no. 1, p. 127.

other alkali, the new axial dimensions are appropriate, but the angular parameters are not. The dependence of the angular parameters on the symmetry of the starting materials results from the fact that the aluminum: silicon distribution in the feldspar framework persists unchanged during the alkali exchange process. All initially monoclinic feldspars when made entirely sodic have cell angles like high albite. Triclinic sodic feldspars, except for high albite, remain triclinic after exchange with potassium which is unlike natural feldspars so far reported. It may be possible to utilize these relations to establish unequivocal criteria for alkali metasomatism, as well as to gain new insight into the crystal chemistry of alkali feldspars.

Crystal-chemistry studies of omphacite, (Ca, Na) (Al, Fe,Mg)Si_2O_6

Refined unit-cell data and indexed X-ray-diffraction powder data for nine omphacites from various eclogites of California and New Caledonia [61] have been compiled by J. R. Clark and R. G. Coleman. An omphacite crystal from one of these specimens (Tiburon Peninsula, Marin County, Calif.) has been used for a complete three-dimensional crystal structure analysis by J. R. Clark and J. J. Papike. Single-crystal techniques show that the true symmetry of this pyroxene is monoclinic, space group $P2$ with a= 9.596A, b=8.771A, c=5.265A, and β=106°56′. It had long been assumed that omphacitic pyroxenes had the normal clinopyroxene symmetry of $C2/c$ such as diopside and jadeite do, and the existence of the lower symmetry in omphacite was not suspected previously.

Least-squares and Fourier refinements of the counter-measured data show that the omphacite structure contains 4 distinct silicate tetrahedra, joined in pairs to form 2 distinct pyroxene-type chains. Within the unit cell there are 4 large and 4 small sites available for Na, Ca, Mg, Fe, and Al. In the $C2/c$ diopside structure, Ca occupies large sites and Mg occupies small sites, but within each unit cell there is only one crystallographically distinct site of each kind. The site occupancies for the present omphacite crystal have been refined, and significant fractionation is found. At least 1 large site and 1 small site appear to contain only 1 kind of cation each, calcium in the former and aluminum in the latter. The degradation of the sites with multiplicities 8 and 4 in diopside to sites of multiplicities 2 and 1 in omphacite changes the symmetry from $C2/c$ to $P2$. This change of symmetry, as well as the cation fractionation, is probably related to the multiple-cation content and to the pressure-temperature history of the eclogites.

[61] R. G. Coleman, D. E. Lee, L. B. Beatty, and W. W. Brannock, 1965, Eclogites and eclogites—their differences and similarities: Geol. Soc. America Bull., v. 76, no. 5, p. 483–508.

Studies on mixed-layer clays

E-an Zen has employed the one-dimensional Ising model to explain the alternation of the different types of layers in various natural phases such as the mixed-layer clay minerals. In a few favorable cases where data exist, application of the Ising formulation leads to quantitative estimation of excess interaction energy (W), and also to the excess chemical potential of mixing. The numerical data required for these calculations are obtained directly from the stacking sequences of the mixed-layer clay minerals as revealed by X-ray diffraction techniques. Presently available information indicates that mixing between montmorillonite and illite dioctahedral layers results in negative values of W, and thus regular alternation of the two types of layers tends to occur. The value of W is positive for mixing of vermiculite and montmorillonite, thus the two types of layers tend to segregate.

Montmorillonitic clays from bentonites and shales of Pierre Shale

Detailed chemical, X-ray, and thermal studies by L. G. Schultz have shown that montmorillonitic clays from the bentonites of the Pierre Shale are normal completely expanding montmorillonite, whereas that from the shales is interlayered with nonexpanding illite and has characteristics both of montmorillonite and beidellite. Montmorillonite of the bentonites has a layer charge due primarily to substitution of Mg for Al in the octahedral layer and exhibits a DTA dehydroxylization endotherm at 700°C. The montmorillonitic clay in the shales has a similar layer charge, but dehydroxylates at 550°C, the characteristic dehydroxylization temperature of beidellite (beidellite however, derives its layer charge from substitution of Al for Si in the outer silica layers). Montmorillonitic clays such as these have been described only rarely in the literature. Their existence suggests that substitution of Al for Si may not be the primary cause of the lower thermal stability of beidellite relative to montmorillonite, as commonly assumed. Confirmation of this suggestion is provided by a synthetic beidellite that gave a dehydroxylization endotherm of 750°C.

Clay mineralogy of weathered granitic rocks

Studies of the clay mineralogy of soils developed on weathered granitic rocks in a variety of climatic settings in the Sierra Nevada, Calif., by R. J. Janda indicate that there is a pronounced vertical zonation of soils and associated clay minerals. The regosolic mountain soils and ando-like soils above an altitude of 6,500 feet have a clay-mineral suite principally comprised of halloysite, illite and vermiculite. The principal clay minerals associated with the reddish-brown lateritic soils at intermediate altitudes are kaolinite and illite; gibbsite is also common, but montmorillonite, vermiculite, and mixed-layer clays are scarce, except in the gruss where they are the dominant clay minerals. In the foothills, the clay minerals associated with the reddish prairie and noncalcic brown soils are kaolinite, illite, montmorillonite and mixed-layer clays, but kaolinite is far more abundant than montmorillonite.

Solubility of kaolinite

W. L. Polzer and J. D. Hem (r2051) found that when a natural kaolinite was exposed to water at pH 3.2 to 4.0 for 2 years, a partial equilibrium was attained. An impurity in the kaolinite, probably a form of amorphous silica, caused the dissolved silica concentration to increase throughout the experiment. The data give a standard free energy for kaolinite of −903 kilocalorie/mole.

Crystal structure of α-spodumene

D. E. Appleman has refined the crystal structure of α-spodumene, $LiAlSi_2O_6$, from Newry, Maine. Scintillation-counter-collected data were used in the refinement. The structure is similar to the pyroxene jadeite but with significant differences in alkali coordination and chain configuration, involving degradation of the symmetry. The aluminum in the mineral is entirely in octahedral coordination.

Crystal structure of shattuckite

The crystal structure of shattuckite, $Cu_5(SiO_3)_4(OH)_2$ has been solved by H. T. Evans, Jr., and M. E. Mrose. The unit cell is orthorhombic, *Pcab*, a=9.88 A, b=19.81 A, and c=5.38 A, Z=4. The structure contains pyroxenelike silicate chains extending along the c axis. The unshared oxygen atoms of the chains and the OH groups coordinate to two kinds of Cu atoms. The type-I copper atoms are octahedrally coordinated, the octahedra condensing by sharing edges to form a brucitelike $(CuO_2)_n$ sheet extending parallel to the a-c plane. The type-II copper atoms are in a square-planar coordination with the opposite edges shared with other CuO_4 groups to form ladderlike $(CuO_2)_n$ chains.

Solution studies of serpentines

Solution studies of chrysotile, lizardite, and antigorite were made by G. T. Faust and Bartholomew Nagy. A reevaluation of the differential solution method for discriminating among these minerals was made, and the stability of lizardite under the conditions of the test was reaffirmed. The method was critically examined both qualitatively and quantitatively on four natural admixtures, and it was found that the technique is capable of quantitatively differentiating between chrysolite and the pair of platy phases, lizardite and antigorite. The platy phases must be identified by X-ray methods.

Studies of hydrous nickel-magnesium silicates

G. T. Faust found that certain minerals of the garnierite group previously described as genthite, röttisite, de saulesite, revdanskite, garnierite, nepouite, noumeite, and noumesite are either the nickel end member of the montmorillonite group (pimelite) or are mixtures of pimelite and the nickel analogs of the serpentine group minerals. Some specimens contain nickelean talc, nickelean chlorite, or nickel-exchanged vermiculite.

Studies of layer silicates

Malcolm Ross, Hiroshi Takeda, and D. R. Wones have completed a systematic description of mica polytypes, including an analysis of a large number of natural samples and development of X-ray powder and single-crystal techniques to identify the various stacking sequences found in these silicates (Ross and others, r1860). Elaborate computer programs have been written so that the crystal structure of the newly discovered mica polytypes may be easily solved. Among the mica structures thus far worked out are the $3T_1[02\bar{2}]$, $4M_2[2220]$, $4Tc_5[0132]$, $8M_8[(222)_2 2\bar{2}]$, $8Tc_1[(0)_6 2\bar{2}]$, $10Tc_3[\overline{(2)_5}\bar{2}2200]$, $11M[(222)_3 2\bar{2}]$, $14Tc[(0)_{12} 2\bar{2}]$, $18M[(222)_5\overline{222}]$, and $23Tc[(0)_{21} 2\bar{2}]$ polytypes.

Coalescence of two or more mica polytypes has been observed in several crystals. For example, intensity measurements show that the $18M[(222)_5\overline{222}]$ biotite is coalesced with a simple $3T[222]$ biotite. The crystal apparently started growth as a 3-layer form, then later the 3T growth ceased and growth as an 18-layer structure proceeded.

Good evidence is accumulating to indicate that many biotites start crystal growth as simple polytypes (1M, $2M_1$, and 3T) but at some later stage in the growth process periodic "mistakes" or coalescence occur when new forms start. This suggests that crystal growth of rock-forming silicates at high temperatures is a rather inhomogeneous process. Study is continuing in an attempt to relate biotite polytypism with the thermal history of the rocks.

Malcolm Ross has refined the crystal structure of a 1M biotite from Ruiz Peak, N. Mex., to a reliability of 10 percent. Bond distances are in good agreement with those predicted from previous work. The refined coordinates serve as a basis for calculation of the crystal structures of the multilayer polytypes described above.

In a study of altered biotite found in weathered ultramafic rocks collected by D. M. Larrabee near Martinsville, Va., Malcolm Ross has found exceptionally well crystallized hydrobiotite and vermiculite coexisting with actinolite and quartz. Single-crystal data show that the hydrobiotite structure consists of two biotite layers separated by a double layer of water molecules. The vermiculite, usually coexisting within the hydrobiotite, has a structure in which a single biotite layer is interleaved with a double layer of water molecules.

Crystal structure of melanophlogite

The crystal structure of melanophlogite, a new polymorph of SiO_2, has been solved independently by D. E. Appleman (r2052) using the symbolic addition procedure of J. Karle and I. Karle. The structure is a clathrate, analogous to the 12-A gas hydrate structure, $Cl_2 \cdot 8H_2O$, confirming the structure model proposed by Kamb.[62] The crystal structure consists of two distinct types of cages, a large tetrakaidecahedral cage and a smaller pentagonal dodecahedral cage. Within the cages are organic "guest" molecules. The silicon atoms in melanophlogite are bonded tetrahedrally to 4 oxygen atoms and play the same role as the oxygen atoms in $Cl_2 \cdot 8H_2O$ where oxygen is tetrahedrally coordinated by 4 hydrogen atoms.

Mineralogy of minasragrite

M. L. Lindberg, John Marinenko, and I. A. Breger have completed a study of minasragrite from the type locality, Cerro de Pasco, Peru. The crystals are monoclinic, $P2_1/a$, with $a=12.95$ A, $b=9.73$ A, $c=7.01$ A, $\beta=110°55'$, V=825 A^3, and Z=4. A new chemical analysis by John Marinenko shows $VO_2=29.8$, $V_2O_5=3.0$, $SO_3=32.0$, $H_2O=34.5$, insoluble=0.62, total=99.9 weight percent. The analysis may be calculated to the formula $V(OH)_2SO_4 \cdot 4H_2O$ or $VOSO_4 \cdot 5H_2O$.

Occurrence of four alkali-magnesium sulfates in Salado Formation, New Mexico

B. M. Madsen (p. B125–B129) has found loeweite ($6Na_2SO_4 \cdot 7MgSO_4 \cdot 15H_2O$), vanthoffite ($3Na_2SO_4 \cdot MgSO_4$), bloedite ($Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$), and leonite ($K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$) in the potash deposits of the Upper Permian evaporite sequence, Salado Formation, New Mexico. This is the first report of loeweite and vanthoffite in the United States.

Techniques in optical mineralogy

R. E. Wilcox, G. A. Izett, and D. C. Noble have extended the usefulness of the spindle stage in determinative mineralogy by the development of several new conoscopic methods for rapid measurement of the optic angle, to be carried out if desired on the same mineral fragment for which the principal indices of refraction are measured. Noble[63] has described a method using a micrometer ocular when the optic plane has been rotated into a vertical position. Wilcox and Izett have found a more general method using stereographic plotting of ocular micrometer measurements.

Crystal structure of $(NH_4)_6TeMo_6O_{24} \cdot Te(OH)_6 \cdot 7H_2O$

H. T. Evans, Jr., has completed a three-dimensional crystal structure determination of a complex ammonium molybdotellurate with the formula $(NH_4)_6TeMo_6O_{24} \cdot Te(OH)_6 \cdot 7H_2O$. The structure is monoclinic, $A2/a$, $a=21.28$A, $b=9.925$A, $c=18.68$A, $\beta=115°40'$, and Z=4. The complex ion $(TeMo_6O_{24})^{+3}$ was found within the structure. It is isostructual with the ion $(H_6CrMo_6O_{24})^{-3}$ reported by A. Perloff of the National Bureau of Standards.

Occurrence of molybdenum at Ambrosia Lake, N. Mex.

Black-stained zones in sandstone which are associated with primary uranium ores at Ambrosia Lake, N. Mex. were found by H. C. Granger and B. L. Ingram (p. B120–B124) to contain as much as several tenths of a percent molybedenum. It appears that molybdenum occurs entirely as MoS_2 and is probably in the form of amorphous jordisite.

Yugawaralite and stellerite

The rare calcium zeolite, yugawaralite ($CaAl_2Si_6O_{16} \cdot 4H_2O$) was discovered by R. C. Erd, G. D. Eberlein, F. R. Weber, and L. C. Beatty in a hydrothermally altered silicious host rock of Mesozoic or Tertiary age near Chena Hot Springs, Big Delta D–5 quadrangle, Alaska. The yugawaralite is closely associated with quartz and with another calcium zeolite "stellerite". The latter mineral has been considered to be a pseudo-orthorhombic variety of stilbite; however, study of this mineral has shown it to be truly orthorhombic with an F-centered cell.

Silica- and soda-rich chabazite from Barstow Formation, California

According to A. J. Gude 3d, and R. A. Sheppard (r2053), chabazite locally dominant in an altered rhyolitic vitric tuff in the Barstow Formation (middle and upper Miocene) has a formula of $Ca_{0.19}$, $Mg_{0.19}$, $Na_{1.64}$, $K_{0.13}$, $Al_{2.46}$, $Si_{9.51}O_{24} \cdot 10H_2O$. This chabazite is enriched primarily in soda and silica relative to the formula of ideal chabazite ($Ca_2Al_4Si_8O_{24} \cdot 12H_2O$). The Si/Al ratio of the Barstow chabazite is 3.86, whereas

[62] B. Kamb, 1965, A clathrate crystalline form of silica: Science, v. 148, p. 232–234.

[63] D. C. Noble, 1965, A rapid conoscopic method for measurement of 2V on the spindle stage: Am. Mineralogist, v. 50, p. 180–185.

that of chabazite commonly found elsewhere in cavities and fractures of basic igneous rocks is about 2. Relatively low indices of refraction and small cell dimensions of the Barstow chabazite are consistent with the high Si content.

EXPERIMENTAL GEOCHEMISTRY

Theory of phase diagrams

E. H. Roseboom and E-an Zen have undertaken a systematic analysis of phase diagrams in multisystems. Roseboom has developed the systematic topological arrangement of fields on a composition diagram for systems of 1, 2, 3, and 4 components.

Zen has developed the topological relations in multisystems of $n+3$ phases for unary and binary systems. A "representation polyhedron" (tetrahedron for a unary system; quadrilateral pyramid for a binary system) whose apices are the $n+3$ invariant points and whose edges and face diagonals are the univariant lines succinctly summarizes all the information. Special cases involving degenerate conditions or multiple appearances of invariant points are reflected in the symmetry of the polyhedron.

Zen has also shown that stable and metastable univariant lines divide the P–T region around a nondegenerate binary invariant point into eight segments. The sequence of metastable assemblages for each segment allows the prediction of phase appearance and disappearance and may explain various anomalies in experimental systems and metamorphic isograds.

Roseboom and Zen, working on P–T nets for ternary systems of 6 $(n+3)$, phases discovered that there were 16 different nets which could be reduced to 5 "representation polyhedra", all in the form of a pentagonal pyramid.

Roseboom briefly examined the problem of multisystems with $n+4$ phases for a binary system and discovered that there are at least 60 possible nets, none of which contains all of the possible invariant points.

Studies of magmatic systems

E. H. Roseboom and P. M. Bell (Carnegie Institution of Washington) have constructed a P–T projection for the system $NaAlSiO_4$–SiO_2 up to 50 kilobars. A significant feature of the diagram is the transition of a eutectic melting relation into a peritectic relation with increasing pressure. Such a relationship indicates that trends of fractional crystallization on melting may change greatly as a function of pressure.

Edwin Roedder (r1744) has discovered that olivine-bearing nodules from basalts from 72 localities throughout the world contain inclusions of dense CO_2 fluid. These inclusions place definite limits on the pressure of the magma at the time of trapping and indicate saturation of basaltic magmas with respect to CO_2, a fact which had immediate bearing on such problems as vesiculation, composition of volcanic gases, origin of phenocrysts, carbonatites and diamonds, the early atmosphere of the earth, and the nature of volcanism on the moon.

B. J. Skinner and D. L. Peck recovered basaltic lava containing immiscible sulfide melts from Alea lava lake, Hawaii, and thus measured the sulfur saturation in a basalt magma. By combining these data with the experimental data for metallurgical systems, they derived a model for predicting sulfur solubilities in silicate magmas.

Increase of niobium during crystallization of basalt-granophyre suites

Analyses for niobium have been completed by E. Y. Campbell for David Gottfried on rocks from four basalt-granophyre suites to study the behavior of niobium during crystallization of a tholeiitic magma where FeO (and TiO_2) are enriched in the successive residual liquids. Variation diagrams showing niobium plotted against the mafic index $\left(\frac{FeO+Fe_2O_3}{FeO+Fe_2O_3+MgO}\right)$ indicate a 3- to 4-fold increase in niobium throughout differentiation in each of these suites. The amounts of niobium in a given rock type vary from one suite to the next and show clear provincial differences. For example, the chilled basalt from Tasmania contains half the niobium content of the chilled basalt from Dillsburg, Pa.

The progressive increase of niobium throughout the differentiation of basalt-granophyre suites is in sharp contrast to the trend found in the highly calcic basalt-andesite-dacite-rhyolite suites of the circum-Pacific orogenic regions. In these highly calcic suites, which show silica enrichment rather than iron enrichment in successive residual liquids, niobium decreases throughout differentiation.

Hot-springs studies

R. O. Fournier investigated the possibility of using the dissolved-silica content of hot-spring and wet-steam well water to estimate underground temperatures. It appears that the silica content of many boiling or near-boiling hot springs is controlled by the solubility of quartz at depth, rather than by the solubility of amorphous silica at and near the surface of the ground. In such springs the silica content of the surface water may allow an estimate of the temperature at which the gas was last in equilibrium with quartz at depth, provided a correction is made for the steam that forms during ascent of the solution from the relatively high-pressure environment underground. The percentage of steam that separates from a given amount of solution may be estimated, using tables for steam and assuming adiabatic cooling along the vapor-pressure curve either at constant enthalpy or constant entropy. Using such steam corrections, combined with the solubility curve for quartz in pure water experimentally determined by G. W. Morey, R. O. Fournier, and J. J. Rowe, the method was applied to three wet-steam wells, and good agreement was obtained between the estimated and measured maximum temperatures at depth. The method may be particularly useful where it is desired to monitor maximum temperatures in wet-steam wells without the costly and time-consuming procedure of putting a temperature probe down each well.

Experimental mineralogy

In a study of the effect of quenching rates, B. J. Skinner has shown that pyrrhotites, homogenized at temperatures of 500°C and 600°C, continue to react down to temperatures of at least 300°C, regardless of the pyrrhotite composition. Samples were quenched to room temperatures at rates of 0.1°, 1.0°, and 10.0°C per minute, with samples removed and quenched in ice water at 50° intervals. Thus, a pyrrhotite equilibrated with pyrite at 500°C, and quenched at a rate of 10.0°C per minute will have a composition which increasingly departs from its initial composition as the temperature drops. These experiments are indicative of the unreliability of the pyrrhotite geothermometer.

Margarita Menzel, guest investigator sponsored by the Argentine Consejo Nacional de Investigaciones Cientificas y Technicas, has calibrated the composition of the $Ni_{1-x}Se$ solid solution as a function of temperature and the activity of selenium. As the unit-cell dimensions of $Ni_{1-x}Se$ have also been determined as a function of composition, $Ni_{1-x}Se$ can be used as an indicator of selenium activity in laboratory studies.

D. B. Stewart has synthesized lithium iron spodumene ($LiFeSi_2O_6$). The optical properties are analogous to those of acmite ($NaFeSi_2O_6$) and ureyite ($NaCrSi_2O_6$). The X-ray pattern of $LiFeSi_2O_6$ is analogous to $LiAlSi_2O_6$, spodumene. The material is stable to at least 1100°C in air and to at least 800°C at 2,000 bars in the presence of H_2O. In contrast, spodumene transforms to β spodumene at 700°C in air and at 570°C at 2,000 bars in the presence of H_2O. The stability of spodumene is undoubtedly extended by the presence of small amounts of $LiFeSi_2O_6$, much as jadeite ($NaAlSi_2O_6$) becomes stabilized by the presence of acmite ($NaFeSi_2O_6$).

D. R. Wones has determined the stability of phlogopite at 100 and 400 bars H_2O pressure. The results indicate that the enthalpy change for the reaction: phlogopite $\rightleftharpoons$ 1/2 orthorhombic kalsilite +1/2 leucite +3/2 forsterite $+H_2O$ is 39,000 ±4,000 calories as opposed to 43,500±2,000 for the analogous reaction: annite $\rightleftharpoons$1/2 orthorhombic kalsilite +1/2 leucite +3/2 fayalite $+H_2O$. This result is in good agreement with data on the stability of other assemblages containing phlogopite.

Electrochemical and ion-exchange studies

Motoaki Sato (r1426) developed an electrochemical geothermometer based on the fact that the electromotive force of a cell containing two minerals which crystallized simultaneously should be zero at the temperature of crystallization. The cell, containing an electrolyte sharing a common element with one of the minerals, is placed in a controlled furnace and the electromotive force is monitored as a function of temperature.

As a result of a theoretical analysis of the charge-transfer mechanism of cells with a semiconductive binary-compound electrode, Sato (r0508) concluded that the half-cell potential of such a compound should be a function of the activities of the elements in the compound as well as the activities of the corresponding ions in aqueous solution. On the basis of this theoretical deduction, he derived a general electrode equation for a binary semiconductive compound as:

$$E_{\mathrm{M_iX_j}}=E^0_{\mathrm{M_iX_j}}+(RT/2\mathrm{ij}F)\ln[(a_{\mathrm{M^{j+}}})^{\mathrm{i}}_{\mathrm{aq}} \cdot (a_{\mathrm{X}})^{\mathrm{j}}_{\mathrm{M_iX_j}}/(a_{\mathrm{X^{i-}}})^{\mathrm{j}}_{\mathrm{aq}} \cdot (a_{\mathrm{M}})^{\mathrm{i}}_{\mathrm{M_iX_j}}],$$

where

$$E^0_{\mathrm{M_iX_j}}=\tfrac{1}{2}(E^0_{\mathrm{M,M^{j+}}}+E^0_{\mathrm{X^{i-},X}})$$

The agreement between the theory and the observed potentials is good and resolves many of the problems of sulfide electrode potentials.

Sato has also shown that binary sulfides can exist metastably in aqueous solutions, and has used electrode potentials to measure the metastable equilibria and has used these results in the interpretation of supergene sulfide mineral assemblages.

A. H. Truesdell, P. B. Hostetler, and C. L. Christ have developed an electromotive-force cell for determining the dissociation constants of aqueous ion-pairs. The method employs a cell made up of a cation-sensitive electrode, the electrolyte solution of interest with Cl^{-1} present, and an Ag-AgCl electrode. For the determination of the extent of KSO_4^{-1} formation in aqueous solution, the following cell

$$K^{+1}\text{ electrode} \mid KCl_{aq}K_2SO_4aq \mid \text{Ag-AgCl},$$

has the potential, E, given by the following equation:

$$E=E^0+\frac{RT}{F}\ln\ (a_{\mathrm{K^{+1}}})\ (a_{\mathrm{Cl^{-1}}}).$$

A. H. Truesdell and E. A. Jenne, using the electrostatic model of monovalent-divalent cation exchange, predicted a correlation between exchange capacity and cation selectivity. Using the data of Ames for various zeolites exchanging Na^{+1} and Sr^{+2} the exchange capacities (E.C.) are related to the exchange constant (K) by the following equation: $\log K = k_1$ (E.C.) $+ k_2$, where k_1 and k_2 are constants for the particular exchange.

Solubility studies

E. A. Jenne has determined the distribution of cobalt between iron and manganese oxides in stream sediments by utilizing dissolution kinetics. In the -60-mesh fraction, manganese and cobalt dissolved as a single phase with a first-order kinetic behavior, but iron dissolved as three distinct phases with first-order rates. In the -9 to -60-mesh fraction only the phases of manganese, cobalt, and two lesser soluble phases of iron were found.

Jenne also determined the rates of extraction of soluble calcium, magnesium, sodium and potassium from saline lake sediments with distilled water. By varying temperature and flow rate, the amount of sodium, potassium, calcium, and magnesium present in minor phases could be determined. All four cations were extracted at first-order rate behavior. Only a single sodium phase was present, but potassium, calcium, and magnesium indicated a second phase which exhibited first, zero, and zero order kinetic behavior, respectively.

Trace-element studies

W. W. Vaughn has developed techniques for quantitatively measuring contents of mercury in the subnanogram range. This technique makes possible the study of anomalous mercury concentrations in geologic environments and in studying the transfer of mercury between bedrock, soils, and the atmosphere.

GEOCHEMISTRY OF ORE DEPOSITS

Role of organic matter in deposition of Mississippi Valley ores

In the past there have been a number of suggestions that organic matter may act as a precipitating agent or source of sulfur for precipitation of low-temperature ores of the Mississippi Valley type. Recently two additional mechanisms of organic interaction have been suggested. B. J. Skinner has proposed that sulfide precipitation is caused by sulfur released upon thermal degradation of organic compounds containing sulfur, such as that contained in petroliferous materials. He envisions that heavy metals were carried as chloride complexes in solution in hot brines until the brines came into contact with organic matter from which sufur could be released, principally as H_2S.

An alternative interpretation is that the ores were derived from connate brines, but were precipitated by the slow reduction of sulfate by methane or associated organic matter. This suggestion evolves from calculations by P. B. Barton based on phase assemblages common to the Mississippi Valley type lead-zinc ores which show that sulfate ion and methane in appreciable amounts are thermodynamically incompatible. Fluid-inclusion analyses as well as the common observation of barite and hydrocarbons suggest that sulfate ion and methane do occur together. Both sulfate ion and methane are very unreactive with respect to redox reactions, and their preservation through geologically significant periods of time at low ($\approx$100°C) temperature is not surprising. Their coexistence does suggest, however, that the ore-forming fluid did not originate in a high-temperature environment, nor attain high temperatures, thereby eliminating the likelihood of a purely magmatic source. Likewise, the ore fluid could not have had a long residence time at very low temperature where sulfate-reducing bacteria could thrive.

Silica activity affects pH

Aqueous silica concentration or activity has a marked effect on the pH of initially neutral, dilute electrolyte solutions (for example NaCl solutions) at elevated pressures and temperatures. J. J. Hemley has found that at high silica activities, such as given by silica gel for example, the aqueous silica and alkali-chloride constituents apparently interact through complexing reactions to cause an increase in acidity 1 to 2 pH units greater than that given simply by quartz saturation under given experimental conditions. This observation of the effect of silica activity on the internal acidity of an electrolyte system has far-reaching implications for hydrothermal alteration and ore formation. Such affects may be a significant cause, perhaps the principal cause, of the hydrogen metasomatism (base-leaching) type of alteration so characteristic of hydrothermal ore deposits.

Fluid inclusions at Bingham, Utah

Edwin Roedder and J. P. Creel have made a study of fluid inclusions in samples from the porphyry copper deposit at Bingham, Utah, and the peripheral Lark lead-zinc deposit, in an attempt to delineate the environment of ore deposition. Although far from complete, the study indicates that the fluids present in this ore deposit varied widely in composition, temperature, and density, both in time and space.

In the copper-molybdenum core of the deposit at Bingham, both the temperatures and the concentrations of salts in solution were higher than at the Lark mine. Filling temperatures for inclusions from quartz-molybdenite-chalcopyrite veins in the core, with 7 or more phases at room temperature, corresponding to over 40 weight percent dissolved salts at the temperature of trapping, are estimated to be well above 350°C. Some of these strong, dense brines evidently boiled at the time of trapping, resulting in the trapping of a much lower density CO_2-rich "steam" containing only a few percent NaCl. At the Lark mine, the temperatures and concentrations of salts were lower, but varied widely, even during the deposition of successive zones of color-zoned sphalerite crystals. No evidence of boiling was found at the Lark mine.

Other than gross salinity, determined with the freezing stage, no quantitative compositional data are available. The daughter crystals of halite, sylvite, anhydrite (?), hematite, and various unidentified opaque minerals, as well as the unique occurrence of liquid H_2S, give some semiquantitative data on the fluids.

Transportation and deposition of uranium in sandstones

E. N. Harshman (p. C167–C173) has evolved a theory of genesis for the uranium deposits in the Shirley basin, Wyoming from chemical studies of ore and host rock. A systematic distribution of uranium, selenium, ferrous and ferric iron, carbon, beryllium, and sulfate sulfur is shown by analytical data on samples of unaltered sandstone, ore, and altered sandstone from a roll-type uranium deposit in the lower Eocene Wind River Formation. Transportation of uranium and other elements in a neutral to slightly alkaline, oxidizing solution and deposition by changes in the Eh and pH of that solution are suggested by the geochemistry of these elements at low temperatures and pressures.

Silver and gold in waste sulfide concentrates

Sulfide concentrates produced as waste in the recovery of a high-grade tungsten concentrate at Big Creek, central Idaho, are rich in silver and gold. Microscopic study of the concentrates by B. F. Leonard and electron-microprobe analyses by C. W. Mead show that most of the silver is present as: (1) inclusions of native silver in pyrite and rarely in sphalerite, (2) inclusions of electrum in pyrite, (3) a substituted element in the crystal lattice of tetrahedrite ("freibergite"), and (4) replacement rims of acanthite on galena, sphalerite, and other sulfides. Gold is present as inclusions of gold-rich electrum in pyrite.

Mercury enrichment in magnetite

G. J. Neuerburg has found that magnetite from the Osgood stock, Humboldt County, Nev., is enriched in mercury relative to the rock in which it occurs. Analyses of the magnetite allow detection of distribution patterns areally related to skarn tungsten deposits around the stock.

Isotopic fractionation in uranium deposits in Colorado and Wyoming

According to J. N. Rosholt, Jr., and others,[64] fractionation of U^{234} is less in samples of uranium ore from a body in the Morrison Formation below the water table in the Slick Rock district, San Miguel County, Colo., than in any other deposit in sandstone yet studied. By contrast, samples from relatively unoxidized ore in nearly dry rock above the water table in the Wasatch Formation in the Powder River basin, Converse County, Wyo., are notably deficient in U^{234} relative to U^{238}; samples of immediately underlying rock are slightly enriched in U^{234}. These relations suggest that U^{234} has been differentially leached from the ore-bearing samples. In a companion study of disequilibrium between uranium and the daughter products, Pa^{231} and Th^{230}, in the same two suites of samples, J. N. Rosholt, Jr., Mitsunabu Tatsumoto, and J. R. Dooley, Jr., interpret the low values for Th^{230}/Pa^{231} in the Powder River basin ore as indicating that preferential leaching of U^{234} has been continuous for not less than 100,000 years.

GEOCHEMICAL DATA

The collection and synthesis of geochemical data are an integral part of the U.S. Geological Survey's research program in geochemistry. Some of the data are assembled from previously published works and integrated with data collected more recently. The recent data are from current research investigations of problems such as the nature of geochemical processes, effects of trace-element environment on animal and human health, and techniques of geochemical prospecting. All current data are stored and retrieved by machine methods and, therefore, made readily available for data syntheses of various kinds. Research is also being directed toward more efficient means of data collection and modern methods of data evaluation and analysis.

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[64] J. N. Rosholt, Jr., A. P. Butler, E. L. Garner, and W. R. Shields, 1965, Isotopic fractionation of uranium in sandstone, Powder River basin, Wyoming, and Slick Rock district, Colorado: Econ. Geology, v. 60, no. 2, p. 199–213.

Geochemical survey of Cambrian and Lower Ordovician rocks of Western United States

A. T. Miesch and J. J. Connor have sampled Cambrian and Lower Ordovician rocks following a hierarchal sampling design covering all or parts of 10 states. These rocks include the basal Cambrian sandstones, Cambrian and Ordovician carbonate rocks, and intervening units of shales and siltstones which are present locally. The sampling design is a preliminary one and was devised in order to determine the efficiencies of various designs that could be used in a final sampling program. Analyses of the major chemical constituents in the basal sandstones, interpreted using analysis-of-variance techniques, indicate that approximately half of the lateral variation for most elements could be described by sampling clusters of stratigraphic sections, and spacing the clusters in the order of 100 miles apart over most of the Western United States. It was also found that, as a rule, stratigraphic variation is larger where the sections are of small thickness. This indicates that a Cambrian sandstone section several tens of feet thick, such as those present in the Black Hills of South Dakota or in the Front Range of Colorado, should be sampled extensively within each stratigraphic section. On the other hand, the same degree of precision in the sampling results may be obtained where the Cambrian sandstones are several thousand feet thick, as in Nevada, by taking relatively fewer samples. The greater variation in the sections of lesser thickness can be attributed to the more rapid facies changes that have occurred higher on the craton.

Computer analysis of geochemical data

An extensive system of computer programs has been developed by the U.S. Geological Survey for statistical description and analysis of petrologic and geochemical data. The system operates from a magnetic tape with standardized format on which the basic laboratory data are recorded. Special symbols are used on the tape to indicate specific cases where numerical data are lacking—such as "less than" values, traces, and "greater than" values. Each of the programs in the system handles the symbols differently, depending on the type of calculations involved. General-purpose programs, allow data revisions of various kinds, selection of specific parts of the data matrix, and augmentation or revision of the data matrix by making data transformations, recalculations, or generating new functions. Other general programs provide elementary statistical computations and graphical displays of the data. Specialized programs provide analysis of variance, polynomial and stepwise regression, factor analysis, and other techniques that have become important in petrologic and geochemical research.

Distribution of minor elements in coal

Peter Zubovic has found in the interior province of the United States a relationship between the distribution of minor elements in coal and the tendency of the elements to form organo-metallic complexes. Elements which form small highly charged ions tend to form stable chelates and to become concentrated near the margins of the basin. Other elements are transported farther into the basin, the distance of transport apparently dependent on the relative strengths of the complexes and the available ligands.

Geochemical survey of Kentucky

J. J. Connor and R. R. Tidball have nearly completed the sampling phase of a reconnaissance geochemical survey of rocks, soils, and certain vegetation in the State of Kentucky. The study is made possible by the extensive coverage of detailed geologic maps now available, providing an excellent geologic framework upon which the sampling can be based. Data now available pertaining to sandstones of Pennsylvanian age indicate that some elements display broad regional variation that can be described by means of a reconnaissance survey, whereas other elements do not. For example, approximately half of the total variance of magnesium, sodium, nickel, and vanadium can be described by sampling at intervals of 50 miles. Other elements display high local variation in the sandstones, but little regional variation.

Metals concentrated by humate

V. E. Swanson, I. C. Frost, L. F. Rader, Jr., and Claude Huffman, Jr., have found (p. C174–C177), from experiments with both natural and chemically extracted humate, that this water-soluble organic material from northwest Florida can sorb between 1 and 17 percent, by dry weight, of cobalt, copper, iron, lead, manganese, molybdenum, nickel, silver, vanadium, and zinc. The mechanism of the sorption is unknown, but the process may account in part for the enrichment of metals in ancient carbonaceous sedimentary rocks. Humate apparently could have acted as a scavenger or sponge for metals during exposure to metal-bearing natural waters before, during, or shortly after deposition.

GEOCHEMISTRY OF WATER

Investigations of the geochemistry of water by the U.S. Geological Survey are directed mainly toward understanding the interrelations of the chemical character of water with the geologic and hydrologic environment. Some of the topics under study include the source of dissolved constituents in precipitation, the influences responsible for the variable composition of lakes and streams, the solution or deposition of minerals by ground water, the applications of chemical thermodynamics and kinetics to natural systems involving water, and the character and occurrence of thermal waters.

PRECIPITATION, SURFACE WATER, AND SUBSURFACE WATER

Composition of atmospheric precipitation

A. W. Gambell, Jr., and D. W. Fisher have studied the chemistry of precipitation in North Carolina, New York–New England, and the Virgin Islands. Over a period of 5 months the rainfall samples collected in the Tar River basin of North Carolina were generally acid. The sulfate concentration in the rainwater ranged from 1.0 to 7 parts per million, and the chloride concentration ranged from less than 0.1 ppm to 4 ppm. Similar compositions were observed in samples obtained from a precipitation-sampling network in the New England–New York area. In the precipitation from both North Carolina and New England–New York there is indication of a correlation between acidity and sulfate concentration. Weekly precipitation samples from the Hubbard Brook watershed, near West Thornton, N.H., contained hydrogen-ion concentrations almost exactly equivalent to sulfate concentrations.

The effect of the ocean is clearly evident in precipitation samples from St. Thomas, Virgin Islands. Chloride rather than sulfate is the dominant anion in rainfall there. The pH values for the first 9 months of 1965 ranged from 5.8 to 8, and dissolved ionic constituents averaged about 50 ppm (as compared with less than 10 ppm in the precipitation from North Carolina and New York–New England).

Dissolved oxygen in White River, S. Dak.

Studies of dissolved-oxygen concentration in the White River at Slim Buttes, S. Dak., by B. H. Ringen indicate that the concentration of dissolved oxygen in the water varies with the time of day. Probably the concentrations observed were related directly to the amount of photosynthesis by algae and other plants. During warm-weather periods, when conditions were favorable for the growth of algae, the concentration of dissolved oxygen in the water fluctuated diurnally from about 60 percent of saturation just before daybreak to about 130 percent of saturation in midafternoon. When algae growth was retarded, during periods of cold weather or when the stream was ice covered, the concentration of dissolved oxygen remained almost constant throughout the day at about 85–90 percent of saturation.

Effect of freezing on composition of South Dakota lakes

L. R. Larson found that freezing was the principal factor influencing dissolved-solids concentration in 26 lakes in eastern South Dakota during the period from October 1964 to September 1965. When the lakes were frozen over, the concentration of dissolved solids in the water under the ice increased although lake levels remained nearly constant. The increases in dissolved solids ranged from 13 to 319 percent, and were related directly to ice thickness and inversely to lake depth. The greatest increases were in shallow lakes. The thickness of ice on the lakes ranged from 1.5 to 3.4 feet, and depth ranged from 2 to about 15 feet. The specific conductance of melted ice from Lake Parmley, in Edmunds County, ranged from 2.62 to 6.25 micromhos/centimeter; this corresponds to a concentration of dissolved solids of about 3 parts per million, or about that of distilled water. Water below the ice had 684 ppm of dissolved solids. Because the ice retained so little dissolved material during freezing, the effect of the ice cover on the residual water was nearly the same as if all the water that froze had evaporated instead.

Closed-basin lakes in Western United States

B.F. Jones (r2054) describes changes in composition of water in the western Great Basin. He has found that individual closed basins have characteristic and distinctive trends in anionic constituents of water, from dilute inflows to "end-point" brines. The major anions in highly concentrated lake and playa waters are each related to the particular lithology and associated weathering processes in the contributing area. Although secondary hydrologic, organic, and precipitation processes may severely alter the composition of the water, these processes do not obliterate the fundamental lithologic control of water composition.

Jones also found that the porosity of lacustrine sediments in the Albert Lake basin, Oregon, may exceed 80 percent in much of the material. Precipitated calcite is abundant, and apparently confined to coarser fractions. Magnesium contributed by river inflow is apparently precipitated with ill-defined alumino-silicate material.

Jones and Shirley Rettig have developed an improved method for determining silica in alkaline brines, and have demonstrated a close correlation of silica content with total CO_2 in brines supersaturated with SiO_2.

Saline ground water in Indiana

R. J. Pickering reports that water in Devonian rocks generally has lower concentrations of dissolved solids than does water from rocks of other systems. Saline water from Pennsylvanian rocks in Indiana is predominantly of the sodium-bicarbonate type if the content of dissolved solids in the water is less than 10,000 parts per million. This water is presumed to have obtained its content of sodium ions from clay minerals in Pennsylvanian shales, through cation exchange. Data obtained so far on the chemical composition of saline water containing more than 10,000 ppm of dissolved solids indicate that the content of bromide in the water varies directly with the content of dissolved solids.

Corrosion and encrustation in water wells

Ivan Barnes and F. E. Clarke report that thermodynamic analysis of samples of water and of encrustation deposits from water wells, together with corrosion studies of well parts, has shown an apparent high degree of correlation between extent of saturation with calcium carbonate and ferric hydroxide and extent of corrosion and troublesome deposition on well screens and casings. Every observed instance of unsaturation with these two compounds has been found to coincide with troublesome corrosion, whereas supersaturation with the compounds is found only in areas of relatively limited corrosion. The data collected to date do not permit evaluation of the relative importance of the two compounds in corrosion and encrustation processes, nor has it been possible to collect much information regarding kinetics of reactions or catalytic effects in the particular environments.

Relation of weathering to water quality

R. G. Wolff has shown that weathering of a quartz monzonite in a low hill near Baltimore, Md., results in the breakdown of the feldspars to form halloysite. Allophane may be an intermediate phase. The composition of dissolved solids in water at two different levels in the hill appears to be controlled by the exchange capacity of the clay minerals present. The exchange capacity is in turn primarily dependent on the hydration state of the halloysite.

In another weathering study, involving glauconite, Wolff had found that pseudomorphs of geothite replace the glauconite. Apparently the constituents released by this replacement are removed in part by the water and reprecipitated in part as a clay mineral.

CHEMICAL-EQUILIBRIUM AND KINETIC STUDIES

Formation of polymeric aluminum hydroxide in water

J. D. Hem and C. E. Roberson have found that the nature of crystalline products formed when solutions containing 12 parts per million of aluminum were titrated with sodium hydroxide depended on the conditions of the experiment. When enough OH was added to give a little more than 3 OH ions bound to each Al ion (pH 7.5 to 9.5), the product was at first amorphous but on aging for 10 days it was altered to bayerite. When the ion ratio of bound OH to Al was between 2.0 and 3.0 (pH 4.5 to 6.5), the solutions appeared to be clear but, after aging of the solutions, crystals of gibbsite a few hundredths to a few tenths of a micron in diameter were identified by X-ray diffraction and use of the electron microscope. The kinetics of the reaction of this polymerized hydroxide with acid showed that still smaller aggregates containing many $Al(OH)_3$ units were present in the solutions after a few days of aging.

Sorption and desorption of metals

Cobalt sorption by hydrous manganese and iron oxides has been found by E. A. Jenne to consist of an initial rapid reaction followed by a second much slower reaction, both being of the first order. These reactions occur either in the presence or the absence of $CaCl_2$ (0.1 to 0.2N). Evidence to date indicates that at least part of the cobalt is sorbed in exchange for structural hydrogen.

The available data on cobalt and zinc sorption by clays and soils can be interpreted as two first-order reactions analogous to that of the hydrous oxides. A critical review of the available data indicates that the hydrous oxides of iron and manganese are the principal controls on the sorption of cobalt, zinc, nickel, and manganese by clays, soils, and sediments, and hence the predominant controls on the concentration of cobalt, zinc, nickel, and manganese in fresh waters and in soil solutions.

THERMAL WATERS

Salton Sea geothermal brine

The reservoir temperature of the Salton Sea, Calif., geothermal brine is about 340°C (H. C. Helgson *in* Roedder, r1597). D. E. White has suggested that, prior to boiling with eruptive discharge, the brine of the reservoir contains about 25 percent or more of dissolved solids. The analysis of a brine that had probably undergone evaporative concentration of about 15 percent because of loss of water in steam included the following, in parts per million: Fe, 3,200; Mn, 2,000; As, 15; Pb, 104; Zn, 970; Ca, 40,000; Mg, 35; Sr, 750; Ba, 200; Cu, 10; Ag, 1; Na, 51,000; K, 25,000; Li, 300; Rb, 169; Cs, 20; NH_4, 482; SO_4, 56; Cl, 185,000; F, 18; Br, 146; I, 22; NO_3, 35; B, 520; U, 0.005; Sb, 0.5; Sn, 0.65; Hg, 0.008; total, 310,000; and pH, 5 to 6 (D. E. White, r1933).

Most of the H_2S in the original brine probably escaped in the lost steam. However, judged on the basis of data from other wells, H_2S probably was a few tens of parts per million, stoichiometrically far too low to precipitate as sulfides all of the heavy metals listed above, especially the Fe, Pb, Zn, and Cu. White has found that dilute waters containing a part per million or more of dissolved sulfide systematically have only traces of heavy metals. These relationships suggest strongly that the abundant heavy metals of the Salton Sea geothermal brine are present as chloride complexes that are stable even in the presence of considerable sulfide. The sulfur-deficient brine of the Salton Sea geothermal area is thus a potential ore-forming solution. However, the production of a large ore deposit from this fluid requires either a huge supply of brine depositing only a small part of its contained metal, or some supplemental sulfur supplied to the site of deposition. Some possible mechanisms for providing supplemental sulfur have been studied by White.

Organic production of sulfuric acid from H_2S

A possible explanation of the abundant sulfuric acid found near the surface in hot-spring systems has been found in the life processes of microorganisms that live in soil containing H_2S that escapes from the hot spring water at the water table. Robert Schoen and G. H. Ehrlich found that the microorganisms in 0.1 gram of soil from Steamboat Springs, Nev., produced the equivalent of 37 milliliters of 0.1*N* sulfuric acid in the laboratory in a period of 3 weeks. Additional field and laboratory investigations are essential to test the role of microorganisms in producing sulfuric acid in natural low-temperature environments.

Polyphosphates discovered in natural waters

Polymolecular forms of phosphate have been determined in water from some mineral and thermal springs, according to C. F. Berkstresser, Jr. Polyphosphates, of importance in the manufacture of detergents, have not been found in cold springs fed by ordinary uncontaminated meteoric water. To date, reported concentrations in thermal and mineral springs range up to 0.8 parts per million, exclusive of the usually determined orthophosphate. Polyphosphate was investigated as part of an attempt to explain anomalous variations in concentrations of iron determined by spectrography and normal laboratory methods.

Hydrology and thermal activity, Steamboat Springs, Nev.

In the Steamboat Springs hydrothermal system, D. E. White [65] has concluded that water of dominantly surface origin circulates deeply in fractured crystalline granitic and metamorphic rocks which are usually considered almost impermeable. The normal decrease in permeability with depth, to be expected in such rocks, is offset in an area of abnormally high geothermal gradient by the increasing temperatures, which facilitate deep circulation by decreasing the viscosity and density of the hot water and by increasing its ability to dissolve SiO_2. The hot springs are influenced by precipitation, water-table relationships, barometric pressure, earth tides, earthquakes, the activity of geothermal wells, and other factors. Many of these factors have broad significance to the utilization of geothermal energy.

The total discharge of the visible springs is only about 65 gallons per minute, in contrast to the total calculated discharge of more than 1,100 gpm. The discrepancy is due in part to discharge of geothermal wells, but much more important is the unseen discharge that occurs below the surface, directly into Steamboat Creek.

Utilization of geothermal energy

The economic potential of a geothermal field depends on the volume and temperature of the reservoir and on the adequacy of the fluid supply. D. E. White [65] has suggested that the supply of fluid may be a more common limitation than the supply of heat. Geothermal fields are classified as hot-spring systems (including Steamboat Springs, Nev., and Yellowstone Park, Wyo.) and as deep insulated reservoirs with little surface expression (Salton Sea geothermal field, California). Hot-spring systems are "leaky" systems, with high permeability near the surface. Deep insulated reservoirs, on the other hand, have permeable reservoir rocks that are capped by insulating and retaining rocks of low permeability. Liquid water, which can be at temperatures far above 100°C because the pressure is elevated, is the dominant fluid in most hydrothermal systems. Steam forms by boiling of the hot water as the fluid pressure rises to the level of that which encloses the reservoir. Dry-steam areas that lack liquid water as the dominant fluid seem to be very rare. Of about 30 areas explored to date by drilling in the United States, dry steam has been proved only at "The Geysers," California.

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[65] D. E. White, in press, Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U.S. Geol. Survey Prof. Paper 458–C.

The optimum environment for a geothermal reservoir includes:

1. A potent source of heat, such as a large magma chamber. A depth of at least 2 miles for the magma chamber provides enough pressure to permit high temperatures to be attained in a hydrothermal system; 5 miles may be too deep for water to circulate and to provide an effective transfer of heat.

2. Reservoir rock with adequate volume, permeability, and porosity, and with an optimum depth of 2,000 to 5,000 feet. The rate of fluid withdrawal from a producing geothermal field is likely to be at least 5 to 10 times the rate of natural discharge from the system. If a corresponding increase in deep inflow cannot occur, pressures, temperatures, and production rates must eventually decline. The effects will be particularly pronounced in small shallow reservoirs that are greatly overproduced.

3. A capping of rock of low permeability, that inhibits convective loss of fluids and heat.

INVESTIGATIONS AT THE HAWAIIAN VOLCANO OBSERVATORY

Eruptions of Kilauea in 1965

Kilauea volcano, Hawaii, erupted twice from the east rift zone during 1965. On March 5, about 33 million cubic yards of lava was spread thinly over about 3 square miles from a number of fissures reaching 4 miles eastward from Makaopuhi crater. Nine more days of eruption left a lake of lava over 300 feet deep in the western pit of Makaopuhi; after drainback the perched lake contains about 6 million cu yd of lava with a depth of about 270 feet.

On Christmas Eve, 1965, the second eruption of the year spread about 730,000 cu yd of lava thinly over 150 acres from several en echelon fissures starting at Aloi pit crater and reaching to the west flank of Kane nui o Hamo about 2 miles to the east. Within about 2 hours the lava that surged into Aloi through a crack cutting the floor formed a pond at least 40 feet deep. As fountaining slowed, almost all the lava drained back into the vent crack, leaving less than 10 feet of new lava plastered on walls and floor. A swarm of earthquakes, many of them felt strongly at the Kilauea summit, started before the outbreak of lava and continued for a week. Epicenters early in the event were near the eastern part of Koae fault zone, but on the second day many of them shifted to near the west end. This pattern of shifting epicenters resembles the behavior of the seismic swarm on the Koae fault zone in May 1963 reported by W. T. Kinoshita (r0776).

Epicenters of 1962 earthquake located

The epicenters of a 6.1-magnitude earthquake on June 27, 1962, near the Kaoiki fault, and of 50 aftershocks selected from the more than 1,600 that were recorded over several following weeks, have been located by R. Y. Koyanagi (r0777) and others. In plan the epicenters are concentrated in an **L**-shaped area that extends west and south from the epicenter of the primary earthquake; all lie to the northwest of the surface traces of northeast-trending Kaoiki fault system. A projection of the foci onto vertical planes suggests a fault plane that dips steeply south from a depth of 3 kilometers to 12 kilometers and has a projected surface trace that extends northwest from the trace of the Kaoiki fault system. This study delineates a structure that trends almost at a right angle to the Kaoiki fault system but which has no known expression on the mountain surface.

Seismic investigations on Hawaii

P-wave velocities in the top of the mantle under the island of Hawaii are 8.2 kilometers per second or slightly higher, as reported by D. P. Hill and W. T. Kinoshita. This value is derived from an analysis of data from seismic-refraction profiles established along the three coastlines of the triangular-shaped island of Hawaii and P-delay recordings on the island net of seismographs from artificial explosions at Amchitka in the Aleutian Islands and Kahoolawe in the Hawaiian Islands. Depth to the M discontinuity varies. It is as shallow as 11–12 km under the northeast coast of Kohala-Mauna Kea. Along the west coast of the island, it is 18 km deep under the flank of Mauna Loa and rises to a depth of 14 km under the Mauna Kea-Kohala saddle. Above the M discontinuity, the basal 4–6 km of crust has P velocities of 7.1–7.2 under the whole area surveyed. Material of similar high velocity rises to within 2 or 3 km of the surface under the volcano summits and major rift zones. Away from the rift zones along the coasts, P-wave velocities increase downward from about 2 km/sec at the surface to about 5 km/sec at a depth of 8 km under the southeast coast of Kilauea, and from 2.5 km/sec to 6 km/sec at a depth of 10 km under the west coast of Mauna Loa.

Field determination of viscosity in basaltic lava

H. R. Shaw joined with T. L. Wright, D. L. Peck, Reginald Okamura, and others of the staff of the Hawaiian Volcano Observatory (HVO) for the first instrumental measurement of viscosity in basaltic lava in the field. The method measured the rotation rate at known torques of a spindle introduced into melt. This was emplaced through a drill hole in the solidified crust of the laval lake formed in Makaopuhi pit crater during

March, 1965. The temperature at the depth of measurement was about 1,130°C. Samples of laval taken from this depth contained roughly 25 percent crystals by volume and several percent vesicles. Rotation rates were measured at two different depths and at torques in the range 1 to 5×10^6 dyne centimeters. The two sets of data agreed remarkably well. The data were converted to apparent viscosities in two ways: (a) before the experiment the viscometer was tested in asphalt tars of known viscosities and calibration charts were constructed, and (b) values were calculated directly from the experimental data on the basis of theoretical analysis of cylinders rotating in fluids. The two methods give good agreement. The results show that the coefficient of proportionality between stress and shear rate, that is the absolute viscosity coefficient, is not a constant. The so-called viscosity then is only an apparent one and varies in such a way as to appear lower at higher shear stresses. The calculated apparent viscosity at a shear stress of 1.7×10^3 dyne cm^{-2} (frequency of about 0.006 revolutions per $second^{-1}$) is about 1.5×10^4 poises, and at a shear stress of 8.8×10^3 dyne cm^{-2} (frequency, 0.067 $rev\text{-}sec^{-1}$) is 5.5×10^3 poises. Extrapolation suggests that the apparent viscosity may approach asymptotically to a somewhat lower value as the stress and shear rate are increased indefinitely. This value cannot be given with assurance from the analysis, but it would appear to be of the order of 4×10^3 poises for shear stresses exceeding 10^4 dynes cm^{-2}.

Measurement of oxygen fugacity

The fugacity of oxygen at different temperatures and at different depths in a series of holes drilled through the thickening crust of the lake of stagnant tholeiitic basalt magma in Makaopuhi pit crater is being measured by a device that operates as an electrochemical cell. The probe was designed by Motoaki Sato, and the field experiments were conducted by T. L. Wright and other staff members. In most profiles P_{O_2} shows a linear increase with reciprocal temperature, suggesting that gas and wallrock are equilibrated in a system closed to hydrogen and oxygen, in agreement with the work of Osborn and his students at Pennsylvania State University. Some holes developed an anomalous zone of high P_{O_2} (10^{-3} to 10^{-5} atm) in temperature range 550°–750°C. This zone is thought to be related to a zone of alteration in the crust of Alae lava lake, which was studied before the probe was available. Core from this alteration zone showed higher magnetic susceptibility, alteration of olivine crystals, tarnishing of ilmenite, and an increase in the ratio of Fe_2O_3/FeO to as high as 0.59, compared to the minimum value at 0.10 in core collected from the temperature interval 900°–1000°C.

Origin of lava coils in recent Hawaiian flows

D. L. Peck reports (p. B148–B151) that lava coils in two recent Hawaiian lava flows formed along shear zones generated between a relatively static block of crust and an adjacent moving block of crust above a flowing jet of lava. Coils that spiral inward in a clockwise direction indicate right-handed shear, whereas those with a counterclockwise spiraling direction record left-handed shear.

ISOTOPE AND NUCLEAR STUDIES

GEOCHRONOLOGY

Age determinations of Precambrian rocks of the northeastern Front Range, Colo.

C. E. Hedge, Z. E. Peterman, and W. A. Braddock have nearly completed an extensive age-determination program on the Precambrian rocks of the northeastern Front Range in Colorado. Precambrian sedimentary rocks of this area have undergone a long and complex geologic history involving multiple periods of metamorphism, deformation, and intrusive activity. The first major event following sedimentation was folding along east-west fold axes, and low-grade metamorphism. Following this event the rocks were subjected to a medium- to high-grade regional metamorphism which was accompanied by the emplacement of syntectonic intrusions typified by the Boulder Creek Granodiorite. Whole-rock and mineral Rb-Sr isochron ages indicate that this event occurred 1.65 billion years ago, as shown by the following determination: (1) Boulder Creek Granodiorite, 1.62±0.07 b.y.; (2) other small syntectonic intrusions, 1.62±0.07 b.y.; (3) concentration pegmatite formed during regional metamorphism, 1.66±0.08 b.y.; (4) schists and paragneisses, 1.65±0.03 b.y.; and (5) intrusive pegmatite, 1.63±0.05 b.y. K-Ar ages of two hornblendes from amphibolites gave slightly lower ages of 1.54 b.y. and 1.51 b.y., perhaps reflecting in part, a later thermal event.

The Mount Olympus and Sherman Granites, and granites of the Silver Plume type, and related pegmatites represent a younger period of intrusive activity. Fourteen whole-rock samples and five minerals from the Log Cabin (Silver Plume type) and Sherman batholiths indicate emplacement at 1.33±0.01 b.y. ago. K-Ar ages of biotite (1.29±0.06 b.y.) and hornblende (1.38±0.07 b.y.) for the Sherman Granite are in accord with the isochron age. Eight whole-rock samples of the Longs Peak granite (Silver Plume type) of the St. Vrains batholith are dated at 1.37±0.02 b.y. Other rocks emplaced during this period of intrusive activity are: (1) muscovite-biotite granite (1.31±0.07 b.y., whole-rock Rb-Sr isochron age); (2) pegmatite (1.31±0.01 b.y., mineral Rb-Sr isocron age); and (3) diabase dikes (1.35±0.07 b.y., hornblende K-Ar age). Following this second period of intrusive activity, the area underwent faulting and local cataclasis. Mineral ages suggest that this late event occurred approximately 1.25 b.y. ago.

Pliocene-Pleistocene boundary in California

W. P. Woodring has suggested that the base of the Lomita Marl Member of the San Pedro Formation be considered as the Pliocene-Pleistocene boundary in California. K-Ar age determinations by J. D. Obradovich on glauconites from 9 zones within the Lomita Marl Member yield a mean of 3.04 million years. In order to establish the validity of this age one must preclude the possibility that glauconite from the underlying lower Pliocene siltstone (Repetto Siltstone of former usage) has been reworked into the Lomite, although the morphology and color of the glauconites in the Lomita Marl Member differ from those in the siltstone. This possibility, however, could not be disproven by the K-Ar method where ages of 3.2–3.8 m.y. were obtained for the siltstone glauconites.

A detailed Rb-Sr study was undertaken to see if additional arguments could be made in favor of an authigenic origin for the Lomita glauconites. Fifty-four Rb-Sr analyses on glauconite and Foraminifera from the Lomita Marl Member and the siltstone have been made. The following results were obtained (error given at the 95-percent confidence level):

Material	Sr^{87}/Sr^{86}
Pliocene siltstone glauconite	0.71127±0.00029
Pliocene siltstone Foraminifera	.70930±0.00026
Lomita Marl Member glauconite	.70976±0.00029

The Foraminifera data give the Sr isotopic composition of Pliocene sea water and are in excellent agreement with the values for modern sea water.

The Rb-Sr concentrations for the Lomita glauconites range from 178–193 parts per million and 39–59 ppm, respectively, and the Rb-Sr ratios range from 3.2 to 4.8. The siltstone glauconite has 215 ppm of Rb and 27 ppm of Sr with a Rb/Sr ratio of 7.8. The means of the Sr^{87}/Sr^{86} ratio for the two glauconite samples are significantly different at the 99.9+ percent confidence level. All of these isotopic and concentration data indicate that the two glauconites are indeed different and that the siltstone glauconite cannot have been reworked into the Lomita beds.

With the available data, Rb-Sr ages can be calculated for these two glauconites. At the 95-percent confidence level the Lomita sample is 3±2.5 m.y. and the siltstone sample is 6±1.5 m.y. The K-Ar and Rb-Sr ages for the siltstone are discordant, showing that deep burial, the late Pliocene deformation, or both, are the cause. The K-Ar age of 3 m.y. obtained for the marine lower Pleistocene of California is now considered valid. G. H. Curtis, of the University of California at Berkeley, has recently determined that an early Villafranchian fauna at Perrier, France, is 3.3 m.y. old. Thus the Pliocene-Pleistocene boundary recommended by the 18th International Geological Congress and that recognized in California may be time equivalents.

Age of ultramafic complexes in southeastern Alaska

M. A. Lanphere has obtained K-Ar ages on biotite and hornblende from eight ultramafic complexes in southeastern Alaska which indicate that the complexes were emplaced during the same igneous event in the middle part of the Cretaceous, probably in the interval 100–110 million years ago. Lanphere also reports that petrographically similar ultramafic rocks were emplaced during the early Paleozoic in at least three widely separated localities in southeastern Alaska.

K-Ar ages from California

F. C. Dodge and R. W. Kistler have obtained K-Ar ages for five coexisting minerals (all the major phases except quartz) from each of two Sierran rocks. The results indicate that pyroxene in the environment represented by the Sierra Nevada batholith may lose rather than inherit radiogenic argon. K-Ar ages of minerals from a specimen of Sentinel Granodiorite from the Yosemite area are: augite, 78 million years; hornblende, 89 m.y.; biotite, 89 m.y.; plagioclase, 81 m.y.; and orthoclase, 88 m.y. Separated minerals from a norite collected east of Fresno, Calif., gave the following ages: hypersthene, 48 m.y.; augite, 96 m.y.; hornblende, 121 m.y.; biotite, 113 m.y.; and plagioclase, 105 m.y.

Age determinations of parts of Amargosa thrust complex

T. W. Stern, M. F. Newell, and C. B. Hunt report (p. B142–B147) that Precambrian augen gneiss in the lower plate of the Amargosa thrust in Death Valley, Calif., has an indicated Pb^{207}/Pb^{206} zircon age of 1,820 million years. Tertiary quartz monzonite and monzonite porphyry intrusive rocks that have invaded the Amargosa thrust complex yielded K-Ar ages of 12 to 14 m.y. on feldspar. Also, biotites in the Precambrian augen gneiss have K-Ar ages of 11 to 14 m.y. and clearly reflect the igneous activity recorded by the intrusions and volcanic rocks. Zircons in the igneous rocks give Tertiary Pb-α ages but have a large probable error due to the uncertainty of measuring lead below 10 parts per million by spectrochemical means.

The determined ages agree well with the stratigraphic and structural relationships determined by the field geologic mapping. However, they are inconclusive in helping to infer whether the igneous rocks were derived by melting of the Precambrian rocks and to what extent associated volcanic rocks were derived by differentiation of intrusions that breached their roofs.

Most-primitive ore lead in the United States

Studies conducted by T. W. Stern, R. S. Cannon, Jr., R. W. Bayley, and A. P. Pierce in south-central Wyoming have shown that galena from the gold deposits of the Atlantic City district contains the most-primitive ore lead known in the United States, having model ages of about 2.75 billion years. Graywacke in the metasedimentary host rocks of the galena-bearing gold deposits yields zircon with a Pb-α age of 2.25 b.y. The host rocks, which include sedimentary iron-formations, are intruded by batholithic granite and quartz diorite. Pb-α ages of zircon from the quartz diorite are 2.2, 3.0, and 3.3 b.y.

Additional age determinations

Many age determinations are carried out by the geochronology laboratories of the U.S. Geological Survey in cooperation with Survey field geologists. The results of these investigations are reported elsewhere in this chapter and are generally listed under the heading "geochronology" under names of States or areas in the index.

Reproducibility in K-Ar ages

G. B. Dalrymple and Kimio Hirooka (r1504) investigated the precision of their age measurements by replication on whole-rock samples of a late Cenozoic basalt. Potassium analyses of 10 chips from one hand specimen had a spread of from 2.53 to 2.61 percent and an average of 2.575 percent; the standard deviation of 0.024 percent shows that variation of age measurement within 1 sample will be <1 percent in two-thirds of the measurements. Similar precision was attained with 12 argon analyses. K-Ar ages of 7 samples of the same basalt, collected at points up to 3 kilometers apart, had a spread of from 3.20 to 3.41 million years, with an average of 3.32 m.y. The variation, shown by the standard deviation, is 0.021 m.y., or 6 percent of the mean.

RADIOACTIVE DISEQUILIBRIUM

Fractionation of uranium isotopes in uranium-bearing sandstone

Isotopic ratios of U^{234}/U^{238}, $Th^{230}/^{234}$ and Pa^{231}/U^{235} were determined by J. R. Dooley, Jr., H. C. Granger, and J. N. Rosholt, Jr., in 30 samples from 5 vertical suites of uranium-bearing sandstone from the Ambrosia Lake district, McKinley County, N. Mex. Uranium-234 variations were as great as 58 percent deficient and as much as 36 percent enriched as compared to the radioactive equilibrium value. The pattern of U^{234} fractionation generally shows an enrichment just above the ore and a large relative deficiency near the richest uranium ore. The values of the isotopic ratios indicate a complicated history of uranium migration in the deposit with significant redistribution of uranium having occurred during the last 200,000 years. The distribution of Th^{230} and Pa^{231} indicates that interphase isotopic exchange of uranium was the predominant mechanism producing U^{234} enrichment, although deposition of U^{234}-enriched uranium from solution can be a contributing factor.

Isotopic fractionation of uranium and its daughter products indicates a more complicated history of uranium migration in the Ambrosia Lake district than in most other uranium-ore deposits investigated for radioactive disequilibrium. Although U^{234} deficiencies of 40 to 60 percent were found in ore from sandstone-type deposits in the Powder River basin, Wyo., the mechanism of U^{234} fractionation appears, primarily, to be preferential leaching of U^{234}.[67] The ore in the Powder River basin was protected from surface weathering and only partly oxidized. The large magnitude of isotopic fractionation appeared to be the result of the slightly oxidizing environment.[68]

Patterns of uranium migration in soil profiles

Isotopic ratios of Th^{230}/Th^{232}, U^{234}/U^{238}, and Th^{230}/U^{234} were determined by J. N. Rosholt, Jr., B. R. Doe, and Mitsunobu Tatsumoto in three soil profiles developed on glacially derived parent material from Minnesota. Results on individual soil horizons show similar trends in the variation of U^{234}/U^{238} and Th^{230}/U^{238} ratios, the predominant features being excess Th^{230} and deficient U^{234} compared to U^{238}. The ratios in 2 profiles, both of the same soil series developed on Peorian Loess, are quite similar even though the 2 sample sites are about 50 miles apart. Variations in the ratios between these 2 profiles is no greater than the variations between samples in the same profile.

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[67] J. N. Rosholt, Jr., A. P. Butler, E. L. Garner, and W. R. Shields, 1965, Isotopic fractionation of uranium in sandstone, Powder River basin, Wyoming, and Slick Rock district, Colorado: Econ. Geology, v. 60, no. 2, p. 199–213.

[68] J. N. Rosholt, Jr., M. Tatsumoto, and J. R. Dooley, Jr., 1965, Radioactive disequilibrium studies in sandstone, Powder River basin, Wyoming, and Slick Rock district, Colorado: Econ. Geology, v. 60, no. 3, p. 477–484.

STABLE-ISOTOPE INVESTIGATIONS

LEAD

Colorado ore leads

New isotopic measurements of Colorado ore leads have been completed by M. H. Delevaux, A. P. Pierce, and J. C. Antweiler (p. C178–C186) on 80 lead minerals. The isotopic ratios were determined by two different techniques (electron bombardment of PbI_2, and thermal emission of PbS), with comparable results. The range in variation of the natural isotopes was many times greater than analytical uncertainties and could be determined fairly accurately. For example, the isotopic ratios of the lead in galena from the Yule marble quarry, Gunnison County, Colo., were 206/204=24.15, 207/204=16.24, and 208/204=41.62, compared to ratios of 15.76, 15.35, and 35.42 for lead from the High Lonesome mine in Grand County, Colo.

Granitic magmas and lead isotopes

The isotopic composition of lead was measured by B. R. Doe in Mesozoic and Cenozoic igneous rocks from the west coast and the continental interior of the United States to determine the possible source rock for granitic magmas in these two distinct areas. The coastal region is typified by a narrow range in isotope ratios that give negative isotopic anomalies, commonly called the J-type. The continental interior region is typified by a broad range in isotope composition, even within an individual magmatic complex such as the Boulder batholith, and by some ratios that are less radiogenic than the coastal region, producing a positive isotopic anomaly commonly referred to as the B-type.

Granitic rocks within the continental interior cannot have formed by complete melting of older granitic rocks if, as suggested by available data in the literature, most Precambrian and Paleozoic granitic rocks had negative isotopic anomalies by Cenozoic time. Such magmatic granitic rocks may have formed by one of the following mechanisms: (1) differentiation from, or partial melting of, a basaltic-gabbroic parent, coupled with crustal assimilation; (2) differentiation or partial melting from a basaltic-gabbroic parent having U/Pb and Th/Pb ratios distinct from continental margins or oceanic areas; and (3) partial melting of rocks of the upper crust. Mechanisms 1 and 2 are favored equally, but Rb-Sr isotope relations in these same rocks militate against mechanism 3. The difference in isotopic characteristics of the granitic rocks in the coastal and continental regions can be explained if, (1) the predominant crustal assimilation takes place in the upper crust through partial assimilation of Precambrian and younger rocks, or (2) some other mechanism occurred, such as partial melting of the mantle in coastal regions and partial melting of the lower crust in the interior regions.

Lead isotopes in oceanic alkali basalts

The isotopic composition of lead and concentrations of lead, uranium, and thorium in oceanic alkali basalts from Easter and Guadalupe Islands have been studied by Mitsunobu Tatsumoto. These basalts form small restricted caps on oceanic volcanoes and range in composition from alkali olivine basalt to rhyolite. It is concluded that: (1) the isotopic composition of lead in oceanic tholeiite suggests that the upper-mantle source region of the tholeiite was differentiated from an original mantle material more than 1 billion years ago, and the upper mantle is not homogeneous at the present time; (2) less than 20 million years was required for the crystal differentiation within the alkali suite from Easter Island; (3) no crustal contamination or assimilation was involved in the course of differentiation of rocks from Easter Island, although some crustal contamination probably took place in the course of differentiation of rocks from Guadalupe Island; and (4) alkali basalt may be produced from the tholeiite in the oceanic region by crystal differentiation. This type of genetic relation, however, may apply only for the oceanic basalts. Alternatively, the difference in the isotopic composition of lead in oceanic basalts may be produced by partial melting at different depths of a differentiated upper-mantle layer.

Billion-year-old feldspar leads

Isotopic composition of lead and concentration of lead, uranium, and thorium in potassium feldspars were determined by Robert Zartman on 20 samples of North American igneous rocks about 1 billion years old. The samples represent a broad spectrum of petrologic types and include only localities having well-documented ages of between 950 and 1,050 million years and with a minimum of postigneous metamorphism. At the time of crystallization most of the leads had isotopic compositions showing small but significant variations yielding apparent Houterman's model ages of between 700 and 1,100 m.y. Several samples with anomalous lead found in small granitic stocks lying within or near much older basement rock are considered to have derived the anomalous lead by a process of partial assimilation of the older rock from which some of the radiogenic lead was removed. Gravitational settling of residual zircon or previous leaching of uranothorite may account for the removal of radiogenic lead from the older basement.

LIGHT STABLE ISOTOPES

Source of carbon at Mammoth Hot Springs, Wyo.

Irving Friedman has shown that C^{13} fractionation between dissolved CO_2, HCO_3^{-1}, CO_3^{-2}, and travertine being deposited at Mammoth Hot Springs in Yellowstone Park, Wyo., is controlled by temperatures that range from 28° to 73°C. The carbon is considered to be derived from marine limestone and the similarity of the C^{13} isotopic compositions in the old travertine terraces and in the modern terraces suggests that marine limestone provided the source of carbon during the life of the springs.

Isotopic correction of C^{14} ages of water

The stable isotopes of carbon have been used by B. B. Hanshaw, Meyer Rubin, and Irving Friedman to correct for solution of carbonate minerals in the dating method for ground water which uses the C^{14} content of the dissolved carbonate species. By means of this isotopic correction factor they are able to determine true rather than apparent ages of water.

Source of hydrothermal waters

Studies by Robert Rye on the O^{18}/O^{16} ratios of hydrothermal calcite and the D/H ratios of water in fluid inclusions in calcite, quartz, and sphalerite from Providencia, Zacatecas, Mexico, strongly point to a magmatic source for the hydrothermal waters responsible for the ore bodies. C^{13}/C^{12} values of hydrothermal calcites indicate a deep-seated origin for most of the carbon in the calcite even though the ore bodies occur in thick sequence of marine limestone.

Metabolic O^{18}/O^{16} fractionation in belemnites

Belemnite guards have been preferred for oxygen-isotope analyses for paleotemperature interpretations because the calcite forming this part of the fossil is coarsely crystalline and less liable to oxygen-isotope changes during burial. For oxygen-isotope studies, no effort has been made to obtain specimens containing a preserved chambered phragmocone occupying a conical alveolus at the blunt end of the guard. The phragmocone has been assumed to be aragonite because the rarely preserved specimens of it have a nacreous luster, although this had not been verified by mineralogic techniques. Belemnites containing well-preserved phragmocones have been provided by R. W. Imlay, and X-ray determinations by H. A. Tourtelot show that the phragmocone are indeed made of aragonite. Carbon- and oxygen-isotope analyses by R. O. Rye show systematic differences in composition between aragonite and calcite in the same belemnite. Oxygen composition relative to the PDB standard from two specimens of the aragonite ranges from −1.8 to −2.7 percent and from +0.6 to +0.8 percent for the associated calcite. If interpreted in terms of temperature, the aragonite was deposited at 25° to 30°C and the calcite in the same animal from 12° to 14°C. If inorganically precipitated aragonite and calcite have identical isotopic behavior, the variations noted in these organic carbonates are evidence of metabolic fractionation of isotopes.

Paleotemperatures for the Late Cretaceous

R. O. Rye and H. A. Tourtelot have found that the C^{13}/C^{12} and O^{18}/O^{16} ratios of aragonite fossils from the western interior of North America show no evidence of latitudinal temperature variation for the Late Cretaceous seas from New Mexico to West Greenland. Benthonic forms always have O^{18}/O^{16} and C^{13}/C^{12} ratios different from those of coexisting free-swimming forms. O^{18}/O^{16} values on benthonic forms give unreasonable paleotemperatures and indicate that their oxygen composition was controlled by vital effects.

TRITIUM

Tritium fractionation in the clay-water system

An isotopic effect has been observed by G. L. Stewart in the clay-water system. Two stages characterize isotopic exchange in clays: a rapid exchange with more labile hydroxyls, followed by slow diffusion and subsequent exchange with other structural hydroxyls. Tritium data show that both isotopic exchange and fractionation occur between adsorbed water and hydroxyls in Davidson clay from near Culpeper, Va. Other clay minerals exhibited exchange, but fractionation was not shown from the preliminary data. After tritiated and deuteriated water had equilibrated at room temperature for 5 days with Davidson clay, the hydroxyl water released in a furnace at 500°C contained about 13 percent as much tritium as adsorbed water. After 17 months of equilibration the hydroxyl water contained over 3 times more tritium than adsorbed water. Deuterium did not fractionate and exchange with hydroxyls to the extent that tritium did. Tritium and deuterium were found to be removed from tracer solution during waterflow in clays. Exchange and fractionation in soil water are insignificant for some hydrologic investigations where great accuracy is not required, but for detailed studies involving microscopic waterflow in clays, corrections for isotopic exchange may be necessary.

HYDRAULIC AND HYDROLOGIC STUDIES

SURFACE WATER

Hydraulic studies of open-channel flow have contributed information on the use of dye to measure time of travel, on the use of the momentum equation in computing the flow of tidal estuaries, and on the friction factor for ripple beds, dune beds, and the underside of ice cover.

Hydrologic studies have helped show how low flow is affected by urbanization and by glacial geology, how the unit hydrograph is affected by channel storage, and how the density of rain gages affects the accuracy of measurement of storm precipitation over the basin.

Tracer studies in rivers

Although the use of fluorescent dye to measure the time of travel of solutes in natural streams is now fairly routine, application of the technique under unusual conditions has revealed additional information on loss and dispersion of the solute and on variations in velocity.

In a 126-mile stretch of the Mississippi River in Louisiana, the longest ever traced with a single slug of dye, M. R. Stewart observed that 25 percent of the dye was lost in the first 20 miles of travel, 40 percent in 60 miles, and very little at distances greater than 60 miles. The amount of dye used, 4,100 pounds of 40-percent rhodamine B solution, was the largest ever used in a stream. C. D. Kauffman and others successfully used the tracer technique on a long reach of the Susquehanna River in New York and Pennsylvania by dividing the 240-mile reach into 12 subreaches and measuring all reaches simultaneously.

In two measurements on a 70-mile reach of the Great Miami River in Ohio, H. P. Brooks found that the dye technique can be used at low flows in a river heavily polluted with industrial wastes. M. R. Collings, on the other hand, found that dye injected into the Otter River in Massachusetts, upstream from the waste outfall of a paper mill, could not be detected 3 miles downstream from the mill; a 100-parts-per-billion sample prepared in the laboratory with river water from the site of the pollution immediately lost about 13 percent of its fluorescence.

J. F. Wilson, E. D. Cobb, and Nobuhiro Yotsukura observed that a slug of dye in the Potomac River estuary at Washington, D.C., was greatly dispersed by tidal action but that the centroid of the dye cloud travelled a net downstream distance of 3.7 miles in a 6-day period. The dye, which was injected near the middle of the 2,000-foot-wide channel, moved toward the left bank during the first day, and the heaviest concentration tended to remain in the left half of the channel during the rest of the period, with little lateral mixing.

R. E. Hogatt found that in several successive reaches of the White River, in Indiana, velocities differed by several fold for discharges with the same probability of occurrence, depending on the presence of manmade structures such as dams and diversions.

Open-channel flow

Sudden changes in stage or discharge, such as those caused by tides or by changes in gate openings in regulated streams, produce unsteady flow and make the usual methods of relating discharge to stage and slope unsuitable.

An example of the effect of unsteady flow was observed by L. L. Laine and C. W. Sullivan in a 3½-mile reach of channel pool downstream from a powerplant in Oklahoma. They found that after the powerplant was shut down abruptly, the flow near the upstream end of the reach reversed its direction for a 15-minute period after the downstream momentum had produced a negative fall of 0.26 foot, but that the flow at the downstream end of the reach continued to be downstream during the period. Under such conditions, discharge can be computed only by considering the momentum of the water as well as the continuity equation for flow in open channels.

Numerical-solution techniques for solving unsteady flow equations on large-scale, high-speed digital computers have been developed by Chintu Lai and R. A. Baltzer. These techniques are now suitable for time-dependent, one-dimensional, and homogeneously dense flow in rivers and estuaries that is analogous to the conditions observed by Laine and Sullivan. Separate techniques based on the characteristic method, the power-series method, and the implicit method are all stable, even when flow resistance is small, and all show good convergence characteristics.

Discharge coefficients for flow in open channels

Using laboratory data, E. V. Richardson and D. B. Simons found that, for flow over a ripple-bed configuration, the Chezy discharge coefficient, C, is a function only of depth and is given by

$$C/\sqrt{g}=10.7 \log D+13.1,$$

in which g is the acceleration due to gravity and D is the depth in feet. The corresponding Manning's roughness coefficients for the depths tested vary from 0.028 to 0.020 as the depths increase from 0.3 foot to 1.0 foot. For a dune-bed configuration, they found that the type of bed material must also be considered, as indicated by the relation

$$C/\sqrt{g}=5.75 \log R/x+6.25$$

in which R/x is the ratio of the hydraulic radius to a roughness parameter that is a function of the ratio of the shear velocity of the flow to the fall velocity of the bed material.

Roughness coefficients for ice cover

K. L. Carey (p. B192–B198) found that Manning's roughness coefficient for the underside of the ice cover on the St. Croix River, in Wisconsin, increased from 0.010 soon after the ice cover formed to 0.028 later in the winter, and he related this change to changes in the ripples and dunes that configure the underside of the ice cover. In computing the roughness coefficient, he divided the cross section into an ice-cover section and a bed section by making a trial-and-error solution of several hydraulic equations, and he made assumptions regarding velocity distribution and hydraulic radius for each section.

Effect of urbanization on low flow

Although the most commonly accepted hydrologic effect of urbanization is an increase in peak flows, urbanization sometimes affects low flow also. Contrary to what might be expected to result from a decrease in pervious area, the low flows on two streams were found to be increased by urbanization. In one instance the increase was due to return flow from domestic and industrial use, and in the other instance it was due to return flow from irrigation.

Under extreme low-flow conditions, according to E. G. Miller, as much as two-thirds of the flow of Assunpink Creek, in central New Jersey, originates at a sewage treatment plant servicing an area that obtains its water from outside the basin drained by the creek. In addition, he found that the return flow from 15 industrial plants along the creek totaled 2 cubic feet per second more than the 38 cfs withdrawn. These findings indicate that the natural low flow of this creek has been increased considerably by urbanization.

Effect of glacial geology on streamflow

Using flow-duration curves for 16 streams in eastern and southern Connecticut, M. P. Thomas (p. B209–B212) established a quantitative relation between flow per square mile at selected duration percentages and the proportion of the drainage basin covered by stratified glacial drift. He found that the flow which is exceeded 94 percent of the time ranges from 0.013 cubic feet per second per square mile, from an area underlain exclusively by glacial till, to 1.30 cfs per sq mi from an area underlain exclusively by stratified glacial drift. For an area underlain by equal parts of till and stratified drift, the corresponding flow is 0.55 cfs per sq mi.

Effect of channel storage on the unit hydrograph

The complicated relationships between channel storage, lag time, and the peak of the unit hydrograph continue to challenge investigators of hydrologic processes, both those who seek to develop empirical relations based on field data and those who analyze the relationships by mathematical and experimental techniques.

Using the empirical technique on data for 17 streams in southeastern Louisiana and southwestern Mississippi, V. B. Sauer found that the lag time needed to define the unit hydrograph can be estimated from the mean length of the basin and a geographical constant, with a standard error of estimate of about 10 percent. The resulting effect on the accuracy of the peak of the unit hydrograph is about 20 percent.

Using an electronic analog model of nonlinear storage, E. J. Gilroy found that for triangular-input hydrographs the time lag between the centroid of the input and that of the output was an exponentially decreasing function of the input peak, such that the time decreased rapidly as small peaks were increased and tended to approach a constant for large peaks. For linear storage the lag time would not vary with the size of the peak. The experimental data were obtained by using a storage-outflow relation of the form $S=KQ^{2/3}$, where S and Q represent storage and outflow, respectively, and by varying the duration of the inflow while keeping the rate of rise and fall of the inflow constant for selected values of coefficient K.

Effect of density of rain gages on determining average precipitation

In a study of the hydrology of a 17.6-square-mile area in central Texas, J. T. Smith found that for two-thirds of 170 storms greater than 0.4 inch the amount of storm rainfall at one centrally located rain gage was within 15 percent of the average of that at 5 gages distributed throughout the area. Similar comparison at 5 other hydrologic research projects on small watersheds in Texas indicates that this result is not unusual.

GROUND WATER

Research on ground water covered a broad range of subject matter, with no single aspect tending to dominate the program. Carbonate-rock aquifers and salt-water–fresh-water relations continued to receive emphasis, as did both laboratory and field studies of the hydraulic and related characteristics of water-bearing materials. The relation of regional and local structure to the water-bearing characteristics of rocks was studied. Research and descriptive studies involving hydraulic and electrical analog models continued. Geochemical and geothermometric techniques of evaluating ground-water movement were studied. "Borehole geophysics" as a means of extracting maximum information from accessible wells and test holes was studied in one project. The increasingly important subject of artificial recharge received attention in a project involving an experimental well. A study in Pennsylvania looked into the cost of developing ground water in relation to source and depth of occurrence of the water. Nuclear explosions were considered as a possible means of accelerating recharge to the Dakota Sandstone, which, in spite of its regional importance, is a rather poorly productive aquifer over the long term, under natural conditions.

Hydrology of carbonate-rock aquifers

M. S. Bedinger and his colleagues studied the geometry of limestone solution by means of electrical analog models based on the geohydrologic conditions controlling the occurrence of water in limestone of Paleozoic age in the central and eastern United States. Analysis of successive models defined the pattern and density of flow and the relative lengths of time of contact of water with rock, and also showed the progressive solution of limestone and the resulting changes in flow. The results support the conclusions that solution channels tend to decrease in size with depth below the water table and distance from the point of ground-water discharge into a stream, and that the largest channels are above or near the elevation of the point of discharge and are more extensive laterally than vertically.

Harold Meisler and A. E. Becher related calcium-magnesium ratios in ground water to the lithology of water-bearing carbonate rocks as an aid to geologic mapping of Cambrian and Ordovician strata in Lancaster County, Pa. Dolomites tend to yield waters having Ca:Mg ratios near 1; limestone, ratios of about 4. The Epler Formation, of alternating limestone and dolomite, showed an intermediate ratio, 2.6.

Analysis of head relationships of four different aquifers in the Venice area, Florida, gave clues to the quality of water in each. W. E. Clark found that inferior quality of water in the "second artesian aquifer" (the third aquifer beneath the surface) is due in part to intrusion of mineralized water from the Floridan aquifer below, which has a higher head, during periods of pump shutdown in wells that are open to both aquifers.

Relations between fresh water and salt water in coastal areas

Several years ago J. E. Upson noted, in certain northern Atlantic coastal areas, apparent departures from the normal Ghyben-Herzberg relation of fresh-water head to depth of fresh water below sea level. In collecting data, or studying available data, to determine whether some of these departures were relict features from early Recent or late Pleistocene stands of higher or lower sea level, Upson found that the position of the interface between fresh water and salt water corresponds closely to the present coastline only in late Pleistocene and Recent deposits (p. C235–C243). In older aquifers the correspondence is poorer, or even remote. Nevertheless, the data seem to indicate that, in all the aquifers, hydrodynamic adjustment of the position of the interface has been rapid enough to keep pace with changes in sea level. The position in a particular aquifer is controlled chiefly by the circulation of water within the aquifer and the location of the areas where water discharges from the aquifer.

J. E. Cotton took advantage of a rare opportunity to observe a complete cycle of salt-water encroachment and retreat. On Great Island, half a square mile of sand connected to Cape Cod, Mass., by a narrow spit, a 35-foot well was pumped for 7 days at 100 gallons per minute. The zone of diffusion between fresh and salt water, which initially lay between 60 and 120 feet below the surface, began to rise within 75 minutes after pumping started, and by the end of the 7 days saline water had risen to a depth of 50 feet. It took 6 months for the zone of diffusion to return to its pre-pumping configuration.

W. F. Lichtler observed that water found in a test well drilled in the well field of Cocoa, Fla., is stratified on the basis of chemical quality. Drilling by the air-lift reverse-circulation method permitted sampling water at specific depths and detecting abrupt changes in chloride content of the water in the Floridan aquifer. For example, the chloride content changed from 2,700 parts per million at 1,380 feet to 690 ppm at 1,385 feet, and to 2,050 ppm at 1,391 feet.

The chemical composition of saline water discharged from certain large springs in the St. Johns River valley, in northern Florida, is closely similar to diluted modern sea water. This fact suggests to F. N. Visher that the salt water below, whose "erosion" by fresh ground water traveling toward the river is responsible for the salinity of the spring water, is ocean water that has traveled through highly permeable rocks from the coast 25 to 35 miles away. Either the rate of travel is so rapid that the ocean water changes little in this distance, or, if travel is slower, it takes place through rocks that have become chemically adjusted to the ocean water and behave neutrally toward it.

Laboratory and field studies of water-bearing properties of porous media

H. W. Olsen continued his study of the parameters controlling flow of liquids in pure clays, the study being a first step in meaningful quantification of flow relations in natural earth materials high in clay content. He developed a new technique of relating flux to gradient in the simultaneous flow of liquid and electric charge through saturated clays under hydraulic, electrical, and ion-concentration gradients. Data on kaolinite consolidated under loads of 50 to 10,000 pounds per square inch show that (1) both liquid and current flows are linear and homogeneous functions of hydraulic and electrical gradients, (2) the effect of liquid flow on electric charge and the corresponding effect of electric charge on liquid flow accord with the expected (Saxon's) relation, (3) liquid flow is proportional to the log of the ratio of ionic concentrations on either side of the clay, and (4) electrical and ion-concentration gradients become relatively more effective, and hydraulic gradient less effective, with decreasing clay porosity and, hence, increasing depth of burial.

In studies at the U.S. Geological Survey's hydrologic laboratory in Denver, Colo., A. I. Johnson determined the effect of entrapment of air and growth of microorganisms in reducing flow through a saturated porous medium. Johnson and Benjamin Reyes found good correlation between particle size and permeability of granular sediments when both dominant particle size and a quantitative expression of degree of sorting were analyzed statistically. In studies of unsaturated permeability they found similarly good correlation between the results of laboratory tests of permeability versus saturation and determinations of moisture tension. R. C. Prill and Johnson were successful in correlating data on moisture tension with specific yields determined by gravity drainage of long columns of sediment and by the centrifuge ("moisture equivalent") method. It was found, however, that moisture-tension determinations themselves are sensitive to temperature, method of sample preparation, and equipment design, and hence must be made under standardized conditions.

Johnson, W. E. Teasdale, and W. K. Kulp, in a continuation of their studies of soil moisture with a neutron probe, determined that the best access medium is a thin-walled aluminum tube barely larger than the probe, installed with a "skintight" fit in a bored or drilled hole. Other types of access holes also were studied, and it was found that results from different types were different but could be correlated with a fair degree of confidence.

S. E. Norris and R. E. Fidler (p. D228–D230), studying the water-bearing properties of glacial outwash at Piketon, Ohio, compared two methods of taking samples for laboratory tests, and also compared laboratory and field determinations of permeability. Samples from bailed-in test holes were found more representative than those from augered holes, but neither retained the full distribution of particle size found in the ground. Laboratory tests yielded permeability values much lower than those obtained in pumping tests of wells. It is concluded that laboratory and field values are comparable only if flow direction with respect to bedding is the same in the laboratory as in the field.

I. S. Papadopulos developed an equation expressing the nonsteady flow of water to a well penetrating an anisotropic aquifer (one in which transmissibility varies with direction). The well is of constant discharge when operated, but is alternately turned on and off. If data are available from at least three other wells, the directions and magnitudes of the transmissibility along principal axes can be computed.

H. H. Cooper, Jr., J. D. Bredehoeft, and I. S. Papadopulos (r1162) developed an exact solution for the response of a well of finite radius to injection of an instantaneous charge ("slug") of water. Comparison of the solution with the slug-test equation described by J. G. Ferris and D. B. Knowles shows that the two equations agree only when more time has elapsed than is generally involved in a slug test. This conclusion confirms results obtained by Bredehoeft by means of an electrical analog model.

O. J. Taylor, in a study of a 250-foot artesian aquifer in the Fox Hills Formation and the basal part of the Hell Creek Formation, of Late Cretaceous age, in eastern Montana, found a reasonably well defined relation between overburden pressure and permeability. The permeability ranged from 22 gallons per day per square foot where the net overburden pressure was 300 pounds per square inch to 3 gpd per sq ft at a pressure of 800 psi.

Structural and lithologic controls on water-bearing characteristics of rocks

Geologic structure, both local and regional, is one of the principal controls on the presence, accessibility, and productivity of aquifers. In crystalline rocks, joints and other fractures are the chief water carriers, and any evidence of their location is valuable in prospecting for water. H. E. LeGrand has developed a system for predicting well yields in the Piedmont and Blue Ridge provinces of the Southeastern States. The system involves a numerical rating based on the topographic situation of the well site and the thickness of unconsolidated overburden. Applied to a graph, the rating indicates the percentage chance for obtaining a given yield. The system was developed by statistical analysis of data which showed that the highest yields generally occur at topographically low sites where residual soils are thick; yields are generally smaller at upland sites, and smallest where such sites are characterized by thin residuum.

E. G. Otton and L. J. Nutter, in a similar study in the Piedmont of Maryland have found that low-yield wells seem to cluster in certain localities where the rocks are relatively homogeneous in lithology or where little saprolitic material is present.

In a study for the U.S. Atomic Energy Commission to investigate the feasibility of storing radioactive waste in chambers excavated in the crystalline rocks beneath coastal plain sediments near Aiken, S.C., at the Savannah River Plant, I. W. Marine (p. D223–D227) has identified two principal types of fractures in the crystalline rocks. Fractures of one type pervade the entire rock mass but are very narrow and create only slight permeability. Those of the other type, restricted to certain zones, are larger and transmit water more rapidly. Some such zones have been correlated from well to well by means of pumping tests.

G. K. Moore and R. H. Bingham have prepared a structural map of the Paleozoic rocks of the Stones River basin, Tennessee. The map shows that the rock formations generally dip downstream and the stream valleys occupy synclines. It is not yet certain whether the synclines are primary, and the stream locations are determined by the structure, or whether the synclines have ben produced by slumping due to solution. No matter which is found to be true, the greatest amounts of ground water are to be expected near the axes of the synclines.

Model studies

It has been pointed out [69] that the only perfect tracer for fluid flow would be a fluid having exactly the same composition as that of the fluid being studied—and hence it would be useless as a tracer. In practical studies of water flow, dilute sodium chloride is a satisfactory tracer for low-chloride water, because the ion tested for, chloride, is affected little by ion exchange or sorption in passing through porous media. J. M. Cahill p. B213–B217) has tested radiophosphorous (P^{32}) and an organic dye in a glycerine base against sodium chloride as tracers. He found that, in sandy media made chemically compatible with the tracer solutions (as by sending a solution of nonradioactive phosphoric acid through the medium before injecting radiophosphorus), the effects of ion exchange and sorption were negligible, so that all three tracers behave well.

E. R. Leggat and M. E. Davis provided the specifications for an electrical analog model of the Hueco Bolson, the alluvium-filled structural trench in western Texas which begins as the Tularosa Basin in New Mexico and extends southward through the El Paso area into Mexico. The alluvium supplies water for El Paso and nearby military installations, as well as for Juárez and environs in Mexico. The model, built at the Geological Survey's computer laboratory at Phoenix, Ariz., satisfactorily reproduced the historical cause (pumping) and effect (changes in water levels) for the periods 1903–53 and 1903–63. The model was then used to predict declines due to pumping proposed for the periods 1963–75 and 1976–90—maximum additional declines of 75 feet by 1975 and 110 feet by 1990.

Geochemistry and geothermometry

Water flowing from certain wells near the south end of Great Salt Lake, Utah, probably entered the outcrop as rainfall or streamflow before the last recession of Lake Bonneville. Water collected by A. B. Tanner and analyzed for C^{14} by Meyer Rubin showed a decrease in C^{14} activity from south to north corresponding to isolation of the water from the atmosphere for 2,000 to more than 30,000 years.

R. W. Maclay and T. C. Winter have analyzed the results of standard water analyses to determine patterns and rates of ground-water movement in glacial deposits in Kittson and Roseau Counties, Minn. Dissolved-solids contents and the ratios of the concentrations of major ions were studied graphically. The results were especially good in showing the location of areas of replenishment of the aquifers.

R. W. Stallman, G. E. Ghering, and R. A. McCullough used precise temperature-measuring equipment to study upward movement of ground water in the Globe, Ariz., and Roswell, N. Mex., areas, as a means of determining the vertical permeability of bedded deposits. Vertical permeability is one of the hydrologic parameters most difficult to evaluate, yet knowledge of it is essential to quantitative studies of hydrologic systems, in most of which movement of water across the beds is important. Thermometric techniques offer considerable promise for solving what has been one of the most stubborn problems of ground-water hydrology.

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[69] C. W. Sheppard, 1962, Basic principles of the tracer method: New York, John Wiley and Sons, Inc. 282 p.

Borehole geophysics

W. E. Teasdale tested a single-detector "tracejector" sonde in several wells penetrating basalt at the National Reactor Testing Station, Idaho. The sonde registered velocities of 0 to 28 feet per minute, and distinguished among upward, downward, cross, and outward flow. W. S. Keys verified the results using a dual-detector sonde. The sondes showed when reversals of flow occurred as a result of changes in rate of injection of liquid waste into a nearby well.

Keys, testing other equipment, found the neutron-epithermal-neutron log superior to the gamma and gamma-gamma logs for supplementing available well logs. The neutron-epithermal-neutron log showed lithologies, and the presence of water, that were not detected by the gamma logs. Gamma-gamma logs made with the probe held against the bore wall were found superior to logs made with the probe suspended in random positions.

Measurements in a well near Mud Lake showed a downward flow velocity of 15 feet per minute. Installing an inflatable packer made it possible to measure heads in the upper and lower parts of the hole and to determine that a head difference of only 0.05 foot was responsible for the flow.

Experimental artificial-recharge well

Philip Cohen and C. N. Durfor (p. D253–D257) describe completion of a uniquely designed well for experiments with artificial recharge of treated sewage-plant effluent, in a study of the practicability of artificial recharge through wells to conserve ground water on Long Island, N.Y. The well was constructed with such materials as fiberglass, polyvinyl chloride, and stainless steel. It will receive effluent treated so thoroughly as to meet accepted standards for drinking water.

Identification and correlation of aquifers

Study of the very productive aquifers of sand and gravel in southwestern Louisiana and southeastern Texas as a regional system has been hampered by inadequate correlation of the strata across the State boundary and the Sabine River embayment. A. N. Turcan, Jr., J. B. Wesselman, and Chabot Kilburn (p. D231–D236) have now succeeded in correlating three of the principal aquifers and two of the principal aquicludes. The correlation will facilitate the construction of an electrical analog model which will be used to study regional recharge, movement, and discharge of the aquifers.

P. W. Johnson and T. E. Williams have identified, from drillers' logs and electrical logs, mainly of oil and gas test holes and wells, that fresh-water aquifers are present at depths of more than 500 feet in lower Paleozoic rocks of parts of the Kanawha–New River basin of southeastern West Virginia and southwestern Virginia. This is a significant discovery in an area of commonly inadequate or poor-quality ground water and flashy, undependable streamflow.

Cost of water from different aquifers

P. R. Seaber and E. F. Hollyday made a statistical analysis of availability and cost of ground water from principal aquifers in the Susquehanna River basin, Pennsylvania. Yields of successful wells range from 15 to 1,000 gallons per minute and the cost at the wellhead, including amortization, from 1 to 11 cents per thousand gallons; the median yield is 150 gpm, and the median cost is 4 cents per thousand gallons. For various aquifers the data showed a median yield of 260 gpm and median cost of 3 cents per thousand gallons, for 11 units of carbonate rocks; 240 gpm and 3 cents for 3 standstones; 45 gpm and 6 cents for 2 shales; 70 gpm and 5 cents for 5 metamorphic-rock units; 110 gpm and 5 cents for 13 units of interbedded sandstone and shale; and 120 gpm and 3 cents for 8 units of interbedded carbonate and clastic rocks.

Hydrologic applications of peaceful nuclear explosions

A. M. Piper, who has studied the potential uses of nuclear explosives in the development and management of water supplies, believes that recharge to the artesian sandstone aquifer of the Dakotas and adjacent States could, in favorable localities, be increased significantly by contained nuclear explosions. These explosions would create "collapse chimneys" which would constitute highly permeable conduits through the confining beds separating the artesian aquifer from other water-bearing strata. Development of such conduits could change the present picture, which is one of a poorly permeable aquifer slowly declining in perennial yield after an initial period of high productivity due to high head.

Piper also calls attention to the possibility of using similar explosions to create collapse chimneys that would intercept brine now discharging into streams in the Permian basin in Texas, Oklahoma, and Kansas. The brine discharge makes unusable a considerable quantity of streamflow which is already of marginal quality.

RELATIONS BETWEEN SURFACE WATER AND GROUND WATER

With more intensive use of water has come an awareness that sound management, planning, and development activities must consider not only the total water available but also the hydrologic adjustments which will take place within the system in response to both natural forces and changes imposed by man. At many places the water in streams, lakes, and impoundments is hydraulically connected with underground water nearby. Changes in stage, storage, movement, and quality of water in either environment may occur as a result of changes in the other. Hydrologic investigations by the U.S. Geological Survey include theoretical and field studies of (1) the contribution of ground water to base flow, (2) methods of forecasting the low flow of streams by the use of ground-water levels and aquifer characteristics, (3) the effects of changes of stage of streams or impoundments on ground-water levels, and (4) other relations between water in the two environments.

Areal distribution of base flow

In studying ground-water contributions to streamflow, the flow of Kansas streams has been separated for each month of record into its two components of base flow and direct runoff. L. W. Furness, C. V. Burnes, and M. W. Busby (r2056) have graphically shown the chance expectancy of various rates of base flow, in any month, at 105 stream-gaging stations in Kansas. Factors causing variations of base flow between stations were investigated by electronic computer. Average annual base flow, for example, was found to be significantly related to length, width and slope of basin, depth of entrenchment, grain size, and mapped values of total mean flow and variability index, with a standard error of estimate of 36 percent.

Effect of bank storage on base flow

In a 19.5-square-mile area of the basin of Four Mile Creek, in east-central Iowa, G. R. Kunkle found that changes in stream stage significantly affect the flood-plain aquifer. The aquifer is composed of alluvial sand capped by silts and clays. Rises in stream stage produce bank storage and delay the normal component of ground-water outflow. Together, bank storage and delayed discharge account for about 35 to 45 percent of the total base flow. The base-flow recession curve is profoundly influenced by these discharge components.

Bank storage related to reservoir operation

Investigation of the hydrology of Hungry Horse Reservoir, Mont., by M. I. Rorabaugh and E. D. Simons discloses that bank storage is large enough to be considered an item in the management of the water of the Columbia River basin. During drawdown of the reservoir, storage from a quarter of a million acre-feet of terrace gravels enters the reservoir with very small time lag. Bank storage from 1 million acre-feet of finer-grained material drains at the slower rate. Seiches in the reservoir cause changes in ground-water levels as far as 800 feet from the shoreline. Theoretical equations and type curves have been prepared by M. I. Rorabaugh to determine aquifer diffusivity from the seiche data.

Water levels related to recharge from streams

Ground-water levels at the National Reactor Testing Station at Idaho Falls, Idaho, respond to changes in the streamflow of nearby areas, according to W. E. Teasdale. Three distinctive types of hydrographs have been related, respectively, to recharge from three nearby drainage basins. A fourth type is a composite hydrograph exhibiting the influence of ground-water flow from all these drainages.

From April through December 1965, 234,000 acre-feet of water from one of these basins, that of the Big Lost River, flowed onto the area in a normally dry channel. According to J. T. Barraclough and R. G. Jensen, the recharge from this flood caused rises of the regional ground-water level of from 1 foot to more than 6 feet over an area of 590 square miles. The perched water level in a well near the Big Lost River rose about 80 feet during the year. Recharge effects were recorded within 3 months, at wells as far as 50 miles south of the river.

Estimation of percolation rates

The effects of present irrigation practices on the Snake River Plain may offer the best clues to the possibilities of artificial recharge to the Snake Plain (basalt) aquifer, according to R. F. Norvitch. Water levels in an observation well adjacent to the Milner-Gooding canal respond to leakage from the canal and to diverted flow from the canal. Seasonal reversals from downward water-level trends occur about 10 to 14 days after the initial filling of the canal in early spring. During the period 1961–65 the depth to the water table at the seasonal low points on the hydrograph ranged from 271 to 276 feet below land surface. Therefore, the apparent vertical velocity of water percolation ranged from 20 to 27 feet per day—a high rate despite the occurrence of a 17-foot-thick layer of volcanic ash which supports a perched water table at about 207 feet below land surface. The apparent coefficient of transmissibility of the saturated basalt in this vicinity, determined by flow-net analysis, is 1×10^7 gallons per day per foot.

Estimation of permeability of a streambed

E. P. Weeks has found, from studies near Madison, Wis., that inflow measurements to a stream following a lowering of stream stage may be analyzed to determine the retardation coefficient, the ratio of the permeability of the less permeable streambed material to its thickness. Values for the permeability of the streambed, computed from this ratio, agree reasonably well with those obtained by analysis of the measured rate of streamflow depletion due to pumping a nearby well, as reported by E. P. Weeks and others (r1629).

Soil-moisture movement near an ephemeral stream

In an investigation of flow losses in an ephemeral stream channel, R. F. Hadley monitored the movement of soil moisture in the unsaturated zone. Using filter paper as a passive sensor, he determined moisture-stress gradients after flood flows in the channel. Gravimetric samples were taken to a depth of 20 feet, both in the channel and on the valley floor. These studies indicate that water infiltrating the channel floor recharges the ground-water aquifer. Moisture-stress gradients in the alluvium underlying the valley floor suggest that moisture is moving toward the surface from a depth of 20 feet.

Ground-water discharge, and depletion of Arkansas River in Colorado

A quantitative field study of the effect of groundwater pumping on the Arkansas River was made by C. T. Jenkins and J. E. Moore. Investigation of a 5-mile reach of the Arkansas River in Colorado showed that a large cone of depression has formed because of the continuous withdrawal of ground water for a municipal powerplant. The water table was lowered below the streambed in part of the reach; thus, hydraulic connection between the river and the water table was broken, and an unsaturated zone developed beneath the channel. Analysis of streamflow and water-level data indicates that change in river stage and change in depth to ground water have little effect on the rate of streamflow depletion in the reach of the stream that is not hydraulically connected with the aquifer. The major control on streamflow depletion is probably a thin layer (less than a foot thick) of poorly sorted material in the streambed.

This study suggests that the limit to the amount of water that can infiltrate from the stream to the groundwater reservoir is directly proportional to the wetted area of the streambed, and that this limit (about 20 gallons per day, as determined from several channel-loss studies) is much smaller than might be estimated by commonly accepted methods.

Spring discharge depleted by use of ground water

According to C. A. Thomas, the total inflow to the Snake River between Milner and King Hill, Idaho, which averaged more than 7,500 cubic feet per second during the period 1910–62, came from the following sources: about 6,000 cfs entered from springs, 100 cfs came from surface waste along the north side, and 1,400 cfs was contributed by springs and from waste on the south side. The total inflow can be correlated closely with streamflow and with irrigation diversion to the Snake River Plain. On the basis of forecasts of streamflow and diversion, it appears that this inflow to the Snake River can be forecast fairly accurately. Also, the inflow for any years bears a consistent relationship to inflow for the preceding year.

Evidence tends to show that recharge disperses rapidly throughout the Snake Plain aquifer and that storage remaining 1 or 2 years after recharge may be small.

Pumping from the Snake Plain aquifer at several places is changing the gradient in the aquifer and reducing the discharge of the springs along the north bank. Water levels in representative wells north of Rupert dropped about 7 feet, and in others north of Hazelton about 14 feet during the period 1958–62. This lowering has been reflected in decreasing spring outflow beginning in 1960.

Chemical quality of stream computed on basis of ground water and overland flow

Variations in the chemical quality of several streams in western New York were found by A. M. LaSala, Jr., and R. J. Archer to be related to changes in the proportion of overland runoff and ground-water discharge, determined by hydrograph separation. Overland runoff was assigned a specific-conductance value based on samples of sheet flow and flood flow in small tributaries. The chemical quality of ground water discharging to the stream was taken from the specific conductance of streams at low base flow. The average daily specific conductance was computed by proportions of the components of streamflow and their corresponding specific conductances. Computed values approximated values obtained from samples collected at gaging stations with drainage areas of 20 to 40 square miles. Results also checked closely with several samples for a stream draining an area of 80 square miles of relatively uniform geology. Computed values of daily conductance compared poorly with a 1-year continuous specific conductance record for a stream draining 145 square miles of varied geology, although average monthly measured and computed values compared within limits of 10 to 20 percent. For larger basins, use of this method is limited to time periods long enough to minimize effects of varied geology, channel storage, and traveltime.

SOIL MOISTURE AND EVAPOTRANSPIRATION

Determination of soil-moisture content

L. M. Shown, R. F. Miller, I. S. McQueen, and William Butler conducted a study using 30 soils developed in alluvial materials which had been derived from several rock types. A semilogarithmic relationship was found between the moisture contents of the soils when saturated and the moisture-retention capacities of the soils as measured in a cooled, humidified centrifuge. This relationship supports the use of moisture-content values of saturated soils as an index of their moisture-holding capacities. Information on moisture-holding capacity is valuable in water-mangement studies on rangelands. Determination of moisture content at saturation is simple and rapid. An additional advantage of this method, as compared with most measurements of soil-moisture-holding capacity, is that coarse fragments up to 2 or 3 centimeters in size can be retained in the soil sample.

Movement of soil moisture

Jacob Rubin and C. D. Ripple developed a digital-computer method for analyzing theoretically the processes of soil-moisture movement which involve simultaneous wetting and drying. With the aid of this method it is possible, for the first time, to analyze quantitatively such processes, while taking into account such major pertinent factors as hysteresis in soil-moisture characteristics. The method was utilized for analyzing the postinfiltration redistribution of soil moisture and the field-capacity phenomenon.

Effect of vegetation on ground-water recharge

R. C. Prill, in a study of gravity flow of water in soils and aquifers in western Kansas, measured the movement of water in unsaturated dune sand using the neutron moisture meter. Preliminary results show the importance of vegetation as a factor affecting recharge. Tracing the movement of moisture from 11 inches of rain that fell over a 36-day period in May and June of 1965 showed the following: (1) under sage vegetation, where root growth is indicated to a depth of more than 16 feet, none of the moisture from these rains was observed to percolate below the root zone, and it apparently was removed by subsequent evapotranspiration; (2) under grass vegetation, where root growth is indicated to a depth of approximately 9 feet, about 1½ to 2 inches of moisture was observed to move below the root zone; and (3) in blowouts which were practically without vegetation, approximately 10 inches of moisture was observed to move as deep percolation.

Effect of salinity of soil moisture on plant growth

In 1964, T. E. A. van Hylckama flushed out six evapotranspirometers containing water of high salinity. Such treatment lowered the conductivity from 20 millimhos per centimeter at 25°C, or more, to about 7 mmhos per cm, which is the conductivity of the water used in the experiment. This was followed by a 30- to 50-percent increase in water use by saltcedar (*Tamarix pentandra*). Three of the six evapotranspirometers were flushed out again in January 1965; the other three were not treated. In the tanks flushed a second time the use of water in 1965 was about the same as it had been in 1964, whereas in the other tanks the use had decreased to about the level of that in 1963. There appears to be a straight-line relationship between water use (y, in centimeters) and soil-moisture salinity (s in mmhos) of the form: $y = 310 - 5.4x$.

Lake evaporation computed by energy-budget method

R. E. Hoggatt and J. E. Heisel have computed evaporation from Morse Reservoir, in central Indiana, by the energy-budget method. They obtained values of 7.5, 5.9, and 2.1 inches for the months of August, September, and October 1965 respectively. The values for the same 3 months from a U.S. Weather Bureau class A evaporation pan at Oaklandon, about 20 miles south, are 5.27, 3.26, and 2.59 inches. Hoggatt and Heisel found that a well-established thermocline existed in the deeper parts of the reservoir, beginning with the initial thermal survey for the energy-budget study and continuing until the middle of September. The variation ranged from 25.5°C at the surface to 11.7°C at the bottom (40 feet deep) on July 22, 1965. By the middle of October the temperature stratification had been erased.

Evaporation losses from reservoirs in Snake River basin

In a study of the water supply of the upper Snake River basin, C. A. Thomas has estimated evaporation losses from storage reservoirs. On the basis of U.S. Weather Bureau data from nearby land pans, and coefficients recommended in Weather Bureau Technical Paper 37, the flow equivalent of evaporation from 8 reservoirs above Milner, in south-central Idaho, for 1963 and 1964 was estimated to average about 500 cubic feet per second or about 5 percent of the available natural supply. Thomas concludes that evaporation losses from reservoirs in the upper Snake River basin are not large enough to be a deterrent to further storage development.

Mass-transfer methods compared with water-budget method to determine water losses from lakes

In a 3-year investigation of Pretty Lake, Lagrange County, Ind., J. F. Ficke has determined a mass-transfer constant N of 0.0056, where evaporation is measured in centimeters per day, windspeed in miles per hour 2 meters above the ground, and vapor pressure in millibars. Comparison of the results of water-budget and mass-transfer studies revealed that seepage into the 184-acre lake during the spring of 1964 was more than 1.2 acre-feet per day. Seepage became negligible during the dryer summer months. The computed annual evaporation of about 31 inches compares well with estimates based upon the data in Weather Bureau Technical Paper 37.

J. F. Turner has estimated that 10 years of mass-transfer data are necessary to determine monthly or seasonal values of reservoir evaporation within about 10 percent. Using records of temperature, relative humidity, and wind collected by the U.S. Weather Bureau at the Greensboro–High Point airport in North Carolina, a 26-year record of evaporation was synthesized. Some preliminary statistics of the synthetic record follow:

Years of record, N	Half 95-percent confidence interval, as percentage of mean		
	July	May–August	Annual
5	13	9	8
10	9	6	5
15	8	5	4
20	7	4	4
26	6	3	3

Suppressing evaporation by destratification of reservoir waters

On June 10, 1965, an air-bubbling experiment to destratify El Capitan reservoir (15,000 acre-feet) near San Diego, Calif., and to maintain destratification, was started in collaboration with the State of California Fish and Game Department, the Helix Irrigation District, and the City of San Diego. For this experiment the sizes of the air compressor and of the air-injection system were the same as those in an earlier experiment [70] at Lake Wohlford (2,500 acre-ft), except that the 90 holes through which the air is injected into the water were spaced logarithmically over a distance of 100 feet of plastic pipe instead of in linear manner over a distance of 60 feet. The air compressor was operated continuously until June 21, when it was shut down for 10 days, after which continuous operation was maintained until October. On June 17, observations of temperature with depth indicated that the reservoir had a difference in temperature of 1.5°C between the surface and a depth of 3 meters, and that below 3 m the temperature was nearly constant to the bottom. The reservoir was maintained in approximately this state of destratification throughout the summer According to G. E. Koberg, the evaporation rate was reduced 23 percent for the period June 18–August 31.

[70] G. E. Koberg and M. E. Ford, 1965, Elimination of thermal stratification in reservoirs and the resulting benefits, with special emphasis on study of Lake Wohlford, California: U.S. Geol. Survey Water-Supply Paper 1809–M, 28 p.

Annual variation in water losses for large lakes

J. J. Ligner reports that during the water year 1965 (October 1964 to September 1965) evaporation from Lake Mead, on the Colorado River, was 74.1 inches. This is appreciably less than the average of 85.2 inches for the period 1953–64. The reduction in annual evaporation is attributed to the operation of Lake Powell, on the Colorado River at the boundary between Utah and Arizona. The temperature of the Lake Mead inflow was much lower in 1965 than in previous years because the water released from Lake Powell is cooler than the water that formerly flowed in the uncontrolled Colorado River. The total volume of evaporation for the period 1953–64 was 10,004,700 acre-feet, or an average of 834,000 acre-feet per year. The annual evaporation ranged from a low of 704,000 acre-feet in 1956 to a high of 1,004,000 acre-feet in 1958. The 1965 evaporation was 602,600 acre-feet, more than 25 percent less than the average for the previous 12 years. On the basis of evaporation data from U.S. Weather Bureau land pans at Page and Wahweap, Ariz., the evaporation from Lake Powell is estimated to have been 300,000 acre-feet during the 1965 water year. Lake Powell, at the end of the water year, contained only about one-third of its total capacity of 27 million acre-feet.

SEDIMENTATION

The scope of investigation termed "sedimentation" includes the sequence of events which begins with the separation of particles from parent rock and concludes with their consolidation into another rock. Sedimentation, therefore, involves consideration of sediment sources; of the weathering, erosion, transportation and deposition of sediments; and of environments of deposition and sedimentary deposits.

EROSION

Erosion of sandstone of the Wynoochee River, Wash.

In silty sandstones exposed in the valley of the Wynoochee River in the Olympic Peninsula, Wash., R. K. Fahnestock observed that wetting and drying, freezing and thawing, or a combination of these processes, appear to be more effective in preparing bank material for removal than does erosion by flowing water. This observation in part extends, to the erosion of bedrock, an observation previously made[71] of the erosion of unconsolidated material.

Scour and fill in stream channels in Mammoth Cave

C. R. Collier and R. J. Pickering have found that erosion of sediment has occurred at some sediment ranges in Mammoth Cave, Ky., and deposition at others. The ranges are located in parts of the cave that are subject to flooding during periods of high water in the nearby Green River. Some scour ribbons placed on the surface of the sediment were later covered by several inches of sediment. Ripple marks observed in the sediment suggested that, under certain conditions, a swirling motion is imparted to the water as it recedes to lower levels of the cave.

TRANSPORTATION

Evaluation of dependent and independent variables in sand-bed streams

A multiple-regression analysis of data from 158 runs of varying flow conditions in an 8-foot-wide flume was carried out by H. P. Guy and C. F. Nordin, Jr. They used sands with a range of median diameter from 0.19 to 0.93 millimeter, and having bed forms ranging from ripples to antidunes. The study was made to determine dependency and interdependency among basic flow and bed-transport variables. On the basis of standard errors of estimates for computed regression equations, Guy and Nordin drew the following conclusions:

1. A strong interrelation exists among transport concentrations, mean-flow velocity, and slope; fall velocity or size of bed material is relatively important but not highly so, and bed-material gradation and depth of flow are of minor significance.
2. Among the many single pairs of variables, the strongest relation is between transport concentration and velocity.
3. Depth of flow is of relatively minor significance in flow in the flume, because of the limited range of depth used in the experiments, but its significance is shown to be important when the regression equations for predicting velocity and concentration are tested against and modified by data from different streams having a large range of depth.
4. Natural stream data are not sufficient to determine whether the results for natural bed-material gradation should differ from those indicated by the flume data.

[71] M. G. Wolman, 1959, Factors influencing erosion of a cohesive river bank: Am. Jour. Sci., v. 257, p. 211–212.

Flood-wave transport of river sediment

K. M. Scott and G. C. Gravlee report that failure of a partially completed rockfill dam in December 1964 released a flood wave at least the equal of any post-Pleistocene discharge on the upper Rubicon River, in north-central California. The diorite rockfill in the embankment of the dam acted as a point source of boulders that are distinguishable downstream. Changes in sedimentological parameters such as mean size, sorting, skewness, and roundness were measured downstream and related to indirectly measured tractive force. Roundness changes were found to be extremely rapid, transition from angular to subangular occurring almost immediately after initiation of movement. The pronounced downstream decrease in mean particle size was due predominantly to progressive sorting. Shot holes in many of the boulders moved from the damsite by the surge identified these boulders and facilitated assessment of the amount of dilution with normal alluvium. En masse movement of rockfill ceased abruptly 1.6 miles downstream, but one boulder was found 2.1 miles below the damsite. Indirect measurements of tractive force along the 61-mile flood course indicate generally decreasing but greatly fluctuating competency. Depositional forms and flow dynamics were strongly influenced by sediment sources, including colluvium, terrace remnants, till, and more than 30 landslides triggered by the surge. Terrace-like boulder berms, associated with macroturbulent transport of boulders in suspension, formed in backwater areas in the uppermost canyon. Boulder fronts up to 7 feet high formed lobate scarps transverse to the channel in an expanding reach, indicating that locally the bed material moved as viscous subaqueous rockflows.

Factors controlling fall velocity of particles in streams

G. L. Stringham, D. B. Simons, and H. P. Guy studied the free-fall behavior of large particles (spheres, disks, oblate spheriods, cylinders, and prolate spheriods) in quiescent liquids. They found that the fall pattern of disks changes systematically, from stable to oscillating to glide-tumble to tumble, as the Reynolds number, R, increases. Stable, transition, and tumble regimes represent increasing degrees of instability. Increases in the stability number of a falling particle (a measure which compares the moment of inertia of the particle with the moment of inertia of an equivalent sphere of the fluid) cause the drag to increase when $R>10,000$. Lead disks, for example, have a greater resistance to motion than aluminum disks of the same size and shape. The drag, or resistance to motion, increases with increasing frequency number for different particles. The frequency number is a measure which compares the diameter of a falling particle and the frequency of its oscillation or rotation during the fall with its fall velocity. Also, the stability of a given particle in the fall path is a function of the shape of the maximum cross-sectional area of the particle and of the Corey shape factor. The study showed that a circular area of maximum projection is more stable than an elliptical or cylindrical cross section, and that stability is inversely proportional to the value of the Corey shape factor.

Step lengths and rest periods of sediment particles in sand-bed channels

The Aris equations for the moments of the longitudinal-concentration distribution have been applied by W. W. Sayre to the cases of longitudinal dispersion of dissolved and suspended dispersants in uniform two-dimensional, turbulent, open-channel flow. The equations were solved by finite-difference methods, using a digital computer. The results obtained to date for dissolved dispersants show that: (1) the overall longitudinal-dispersion coefficient becomes constant only after an equilibrium distribution of dispersant in the cross section becomes established; (2) the dispersion time required for establishment of the equilibrium distribution is $t_e=3Y_n/KU_*$, where Y_n, K, and U_* are, respectively, the flow depth, von Karman's turbulence coefficient, and the shear velocity; (3) the value of the overall longitudinal-dispersion coefficient for $t>t_e$ agrees with the value given by Elder's formula for asymtotically large dispersion times.

Preliminary experiments by F. M. Chang with fluorescent tracer particles and colored lightweight plastic particles indicate that the step lengths of particles which travel as bed load are gamma distributed, and that the duration of the rest periods between steps may be either exponentially or gamma distributed.

Variation in rate of sand transport in gravel-cobblestone-boulder channel

Sand coated with fluorescent paint has been shown to be a useful tool in studying the movement of fluvial sediments. V. C. Kennedy and others added fluorescent sand practically continuously to Clear Creek at Golden, Colo., while collecting sediment samples at a point about 2,600 feet downstream from the point of introduction.

First arrival of the 0.25–0.30-millimeter sand at the sampling point occurred within 20 minutes, and that of the 0.38–0.52-mm sand within 2½ hours. The 0.86–1.0-mm sand required 15 hours to traverse the same distance. Limited data suggest that, for this study, the speed of transport in the 0.3–0.9-mm size range varies inversely with the square of the diameter of the sand grains. As sand size decreases below 0.3-mm, the speed of transport can be expected to approach that of the water.

Although the coarser sand travels more slowly than the finer sand, it also mixes more thoroughly across the stream. This is shown by the fact that for the coarser sand there is less variation in concentration of fluorescent grains in the cross section at the sampling point than for the finer sand.

Sediment loads calculated from dilution of fluorescent sand grains were approximately twice those determined from samples of suspended sediment in the 0.25–0.52-mm size range. In the 0.15–0.18-mm size range the fluorescent-grain method indicated a load only about 30 percent greater than the standard method. The difference in loads calculated by the two methods is attributed to the fact that the fluorescent-grain method measures total load for a specified size range, whereas the standard method measures the suspended load.

Rate of sand transport and changes in bed form

In a recirculating plastic flume that is 10 meters long and has a cross section 20 by 20 centimeters, with water flowing at increasing and then decreasing increments of flow over a planed bed of 0.30-mm sand, R. E. Rathbun and H. P. Guy made the following observations:

1. As velocity was gradually increased, there was no movement of the sand particles prior to ripple formation.
2. At a specific velocity, the ripples started at the upper end of the flume and developed progressively downstream.
3. After ripple development, a given uniform velocity resulted in considerable variation in the amount of sediment transported from the end of the flume.
4. As velocity was decreased in stepwise fashion, the mean velocity for cessation of particle movement on the rippled bed was about half that for beginning of motion on the plane bed.
5. The shape of the ripples and the relative friction factor were not affected appreciably by decreas-

ing the mean velocity to the point of cessation of particle movement.

PREDICTING SEDIMENT DISCHARGE OF NATURAL RIVERS

Equation for computing total bed-material discharge

F. M. Chang, D. B. Simons, and E. V. Richardson determined that the total bed-material discharge, q_t, can be expressed by the equation $q_t=K(t_o-t_c)\ U\ (R+1)$, where K is an experimental coefficient that depends on the bed material and $(c/\sqrt{g})\ (t_o/\Delta\gamma d)S$ for flume data, but is a constant for natural rivers; t_o is the shear stress on the bed; t_c is the critical shear stress at beginning of motion; U is the mean velocity of flow; and R is the ratio of suspended to contact transport. $c/\sqrt{g}$ is the Chezy discharge coefficient, and $\Delta\gamma d$ is the predicted sediment transport rates that were consistent and satisfactory when compared with flume and river data.

Digital-computer method for computing suspended-sediment discharge

M. D. Edwards is studying development of a digital-computer method for computing sediment discharge. Results to date show that the sediment-concentration curve usually generated by manual and graphical methods can be mathematically duplicated with a good degree of accuracy. Two mathematical models have been developed, one for use in the study of streams characterized by large drainage areas and for extended storm events, and one for small basins and brief storms. The large-basin model has proved more accurate.

VARIABILITY OF SEDIMENT LOADS IN RIVERS

Seasonal variation in concentration of suspended sediment

In a preliminary analysis of sediment discharges for selected subbasins in the Susquehanna River, Pa., K. F. Williams found that at least 70 percent of the annual sediment load is discharged during the period November-April. However, preliminary concentration data indicate that, for major streams in the Piedmont province within the basin, below-average concentrations that occur during the May-October growing season are higher than those that occur during the winter dormant season. For major streams in the remainder of the basin, below-average concentrations that occur during the dormant season generally are the higher.

Sources of turbidity in Russian River basin

J. R. Ritter found that persistent turbidity in the Russian River, Calif., was caused largely by diversion of turbid water from the Eel River into the East Fork of the Russian River. Other minor factors included the effects of storage releases from Coyote Reservoir, gravel mining, and algal blooms. He also reported high concentrations of suspended sediment near the bottom of Lake Mendocino, and evidence of turbidity currents which may be responsible for the increase in turbidity in the outflow from the lake after storms.

Urbanization and sediment load

Sediment loads observed in the upper Northwest Branch of the Anacostia River, Md., near Washington, D.C., have continued to increase significantly for the third straight year, in this area of intense urban development. According to D. H. Carpenter, the average annual sediment yield of 2,200 tons per square mile in 1965 represents a 20-percent gain over 1964, and it is almost a 5-fold increase over the yield of 470 tons per square mile in 1962.

Highway construction and sediment load

Russell F. Flint reports that highway construction was a major cause of an increase in suspended-sediment discharge in Alum Creek at Columbus, Ohio, for the period May–September 1964. Direct runoff for this period was only 11 percent greater than that for a similar period in 1961, whereas the sediment discharge increased by 60 percent. Embankments of a highway being constructed immediately upstream from the water-data station are within 10 feet of the stream banks, and the total surface area under construction represents less than 0.1 percent of the total drainage area.

Strip mining and sediment load

In determining the effects of strip mining on the hydrology of the Beaver Creek basin, Kentucky, C. R. Collier reported that there has been no reduction in the sediment yield from the strip-mined area. The weighted mean sediment concentration of Cane Branch, in direct runoff from summer-type storms from June 1956 to June 1959, was 4,760 parts per million. Additional mining in 1959 caused the mean concentration to increase to 19,900 ppm during that summer. In 1960 the mean concentration from the summer-type direct runoff decreased to 5,410 ppm, and it remained at that level through 1964.

VARIABILITY OF SEDIMENT YIELD IN DRAINAGE AREAS

Studies in the Upper Mississippi River and Ohio River basins

Streams in the Upper Mississippi River basin have a wide variation in sediment yield. In a study of sediment data from 60 stations throughout the basin, C. R. Collier found average annual sediment yields ranging from less than 40 tons per square mile in northern Minnesota and northern Wisconsin to 2,300 tons per square mile in central Iowa.

J. H. Klingler, in a detailed study of observations at 45 stations in Wisconsin, observed a significant difference in the average suspended-sediment yield between streams in the northern and southern parts of the State. Streams in northern Wisconsin, draining heavily wooded and sparsely populated areas, have a suspended-sediment yield of 2 to 38 tons per square mile. Yields from the more heavily populated, agricultural southern half of the State average 12 to 600 tons per square mile.

Russell F. Flint reports that sediment records for Raccoon Creek, near Fincastle, Ind., show an average of 1,480 tons per square mile for a 4-year period. On one day, March 21, 1962, the computed daily load of 260,000 tons represented one-third of the total for the 4-year period. On this day, observed suspended-sediment concentrations exceeded 25,000 parts per million for 7 of the 13 observations made.

Studies of Eel River basin

Analysis of suspended-sediment data for the 1958–62 water years indicates that streams draining the coastal area of northern California contribute more sediment than was previously supposed. Preliminary computations by N. L. Hawley and B. L. Jones indicate that the greatest sediment loads are transported by the Eel River and its tributaries. Annual sediment yields in the Eel River basin range from about 1,400–3,000 tons per square mile in the headwaters to more than 8,000 tons per square mile in the lower basin.

DEPOSITION

Storage in reservoirs

Investigations of sediment deposition in East Park and Stony Gorge Reservoirs, in upper Stony Creek basin in California, by J. M. Knott and C. A. Dunnam, show a yield on the order of 0.3 acre-feet per square mile of drainage area. Reduction in storage capacity in each of the reservoirs is about 0.1 percent per year.

The effects of impoundment on the sediment load of a river are demonstrated in a study by M. P. Molnau of suspended-sediment records for the Iowa River at Iowa City, Iowa. The average annual suspended-sediment load for the 15-year period 1943–58 was 1,043,093 tons. In the 6-year period 1958–64 since closure of the Coralville Dam, 9 miles upstream, the annual load has averaged 390,682 tons. Corresponding average annual water discharges for the same periods were 575,585 cfs-days (1,577 cubic feet per second) and 699,529 cfs-days (1,917 cfs), respectively. The average of the annual maximum daily loads decreased from 66,200 tons for the early period to 30,000 tons for the later period. Particle-size analyses show a trend toward finer sizes in the later period which is attributed to trapping of the coarser sediments in the reservoir.

Channel forms and structures, Wynoochee River, Wash.

R. H. Fahnestock has found in his study of channel forms of the Wynoochee River, Wash., that sinuous reaches are characterized by bank erosion of as much as 20 feet or more per year, and by wide expanses of bare gravel and bars 6 to 8 feet above the bottom of the channel. These sinuous reaches are interspersed with narrow reaches, straight or gently curving, some of which have been stable at least 100 years. There appears to be an approximate continuity of gravel transport in both types of reaches. The form and changes of active bars, in reaches immediately adjacent to the stable reaches, indicate that the large quantity of debris moving in these unstable reaches is not stored within them. P. A. Glancy heard the sounds of moving gravel in one of the stable reaches during high water, and also noted a new crop of sandstone concretions, derived from bedrock, in the stable reach after the high flow. These concretions disintegrate upon drying, so they are not available for subsequent movement as gravel.

Climbing-ripple structure

E. D. McKee (p. D94–D103) has made field studies of the occurrence and significance of climbing-ripple structure in the flood plains of the Colorado, Mississippi, and Indus Rivers. Climbing-ripple lamination is a type of stratification in which ripple crests of successive ripple laminae, as seen in a section parallel to the direction of current movement, appear to be advancing upslope. Two factors—velocity of water, and sediment load—control its formation and distribution. McKee has concluded that the structure seems to be limited to a few specific environments and is rare or absent in others, and therefore is a valuable aid in the interpretation of depositional environments.

LIMNOLOGY

Temperature studies of incompletely circulating lakes

Monthly temperature observations in Green and Round Lakes near Fayettville, N.Y., by W. H. Diment, reveal the usual divisions of a meromictic lake: an upper zone (mixolimnion) in which the water circulates twice a year, a chemocline in which the salinity increases rapidly with depth, and a lower zone (monimolimnion) which is traditionally regarded as stagnant or nearly so. The precision of the temperature measurements (better than 0.01°C) permits several unusual observations:

1. With the onset of ice cover the monimolimnion divides into several horizontal isothermal zones separated by sharp boundaries from those above and below. The number of zones and their persistence into the summer differs in the two lakes.

2. The region of the monimolimnion near the chemocline warms through the spring and summer, and even during the fall when the mixolimnion is cooling. This feature thought to be the result of the opacity of the bacterial plate that exists in the chemocline disappears during the winter period of ice cover.

3. The temperatures on the bottom exhibit an annual variation of a few tenths of a degree, but the amplitude and phase of the variation at a given location depend on the depth of water.

Stratification in Lake Cachuma, Calif.

The temperature structure of Lake Cachuma, in Santa Barbara County, Calif., was investigated by G. G. Ehrlich and K. V. Slack following an intense autumn storm. Before the storm the reservoir was thermally stratified, and the concentration of dissolved oxygen in the hypolimnion was very low. At the time of the study, uniform temperatures and generally high concentrations of dissolved oxygen showed that the water was circulating, although a pool of unmixed water at the bottom, near the dam, was identified by its low dissolved-oxygen content. The presence of this unmixed water was attributed to protection from the storm winds afforded by the dam, which is at the western (upwind) end of the basin.

Winter diatom growth in Pretty Lake, Ind.

In winter studies of ice-covered Pretty Lake, La Grange County, Ind., R. G. Lipscomb (p. D242–D249) described a population of diatoms at a depth of 10 meters beneath the surface. Because of the very low light intensity at this depth, Lipscomb suggests that the diatom population was maintained by external sources of organic nourishment (heterotrophy) rather than by photosynthesis. With the exception of silica, water-chemical data did not correlate with fluctuations in the algal population.

Reconnaissance of Desolation Canyon, Green River, Utah

F. E. Clarke and K. V. Slack made a limnological reconnaissance of the Desolation Canyon reach of the Green River between Sands Wash Ferry and the town of Green River, Utah, during October 1965. The specific conductance of the water increased from about 810 micromhos at the start of the trip to about 900 micromhos at the end. This difference is attributed to the influence of the largest tributary, the Price River, whose water had a specific conductance of 4,000 micromhos. The river was saturated with oxygen (with respect to the atmosphere) during both day and night. Temporary increases of 0.5 to 1.0 parts per million in dissolved oxygen were measured with an oxygen electrode when going through some of the rapids, but no measurable increases were found in other rapids of similar appearance. No vertical gradients of temperature, specific conductance, or dissolved oxygen were found in water depths as great as 2.5 m. The biology resembled that of other large unpolluted rivers except that both plants and animals are concentrated in the shallow marginal zones of pools and rapids.

Chemical changes in a laboratory stream

The concentration of dissolved nutrients decreased exponentially in a recirculating laboratory stream during the month following seeding with algae. G. G. Ehrlich, D. E. Donaldson, and K. V. Slack report that the nutrient decrease was accompanied by a rapid growth of diatoms and green algae and also by a rise in the fluorescence of the water.

Death of gars in Everglades National Park

Death of more than 2,000 Florida spotted gar, *Lepisosteus platyrhincus*, resulted from an infestation by a previously undescribed species of blood-sucking fish parasite, *Argulus* n. sp., at Royal Palm Pond, Everglades National Park, Fla. According to M. C. Kolipinski and A. L. Higer, the factors that probably influenced the population explosion of the parasite were the abundance of hosts (gar) and the lack of predators on *Argulus*. A concentration of gar in the pond immediately before the fish kill was related to a drought which had produced the lowest water levels observed during the 5 years of record.

Fish-mortality studies in California

W. D. Silvey and G. A. Irwin, in cooperation with the California Department of Fish and Game, investigated the cause of the annual summer mortality of striped bass in the Carquinez Straits. Chemical studies indicated a very sharp salinity gradient in the area of greatest mortality. No toxic metals were found. It was concluded that the bass were killed by naturally occurring toxic substances (such as hydrogen sulfide) which were produced in the region of the salinity gradient.

In another study, Silvey investigated excessively high mortalities of salmon and steelhead eggs and fry at the California Department of Fish and Game hatchery on the Trinity River. The deaths were traced to acidosis resulting from high concentrations of carbon dioxide in the hatchery water. When the carbon dioxide was converted to bicarbonate by a chemical treatment, the losses of eggs and fry were reduced to normal levels.

GEOMORPHOLOGY

Vigil Network in the United States

As part of the U.S. Geological Survey's participation in International Hydrological Decade activities, a Vigil Network [72] of small drainage basins and other selected sites is being established for long-term monitoring of hydrologic and geomorphic processes. There are now 58 sites throughout the country where data on hillslopes, receding cliffs, pediments, and stream channels are being collected. Studies are also being made of climatology, land denudation, soils, and vegetation. As reported by R. F. Hadley (r1093) at the International Symposium on Representative and Experimental Basins, in Budapest, Hungary, in October 1965, the Vigil Network activities consist of the following: (1) measurement of channel geometry, scour and fills, and peak flows at 57 sites (2) measurement of erosion, cliff recession, and mass movement on hillslopes at 48 sites; and (3) study of relation of vegetation density to land use and climate at 13 sites.

L. B. Leopold and W. W. Emmett (r1714) describe a sample of data from a Vigil Network site in Wyoming, prepared for permanent filing as a United States contribution to the International Hydrological Decade. The observations provide a basis for observation, through time, of the erosion of an ephemeral stream channel.

Stream-power index for geomorphic analyses

J. T. Hack has devised a rough index of stream erosive power especially useful in geomorphic analyses. By its use, topographic maps can be converted into isopleth maps showing zones of equal stream power or erosional energy. Hack's index is based on the tendency of streams in the Eastern United States to exhibit longitudinal profiles, or parts of profiles, that approximate logarithmic curves He derives his index of erosional energy by measuring the stream length at a locality (defined as the distance from the source along the principal stream of the watershed) and multiplying this value by the channel slope at the locality (from the topographic map). The product obtained, termed the "SL value," is proportional to the power of the stream. In effect, it is an approximation of what the gradient would be if all the discharge in all the streams were uniform.

Isopleth maps of a large field of SL values generally show highs and lows related to outcrop areas of rocks of different resistance to erosion. Traverses across such a map of the Globe quadrangle, North Carolina, show that many areas of anomalously high values correspond to lenses of feldspathic gneiss too small to be shown on the published geologic map but which cause steep slopes or knickpoints in the streams. Other differences in SL values are unrelated to rock resistance but seem to reflect unknown causes of differences in stream-erosion rates in different areas. The method may serve a variety of uses in geology, geomorphology, and hydrology, and increase the usefulness of topographic maps.

Stream profiles

C. W. Carlston has plotted longitudinal profiles of more than 10,000 miles of streams in the United States, south of the glacial border and between the Rocky Mountain front and the eastern edge of the Mississippi embayment. Points plotted on rectilinear paper at 10-mile intervals showed three types of profiles (1) straight; (2) concave up and smooth; and (3) concave up and irregular, in the headwaters. Excluding ungraded headwaters, about 75 percent of the plotted profile distance was made up of straight segments; the remainder was concave.

Drainage density and climate

Sir C. A. Cotton [73] has pointed out that C. W. Carlston,[74] in his paper on drainage density and streamflow, placed insufficient emphasis on the effect of climate upon drainage density. Carlston has subsequently reevaluated drainage density versus base flow in the 15 basins originally studied. The new study reveals strong evidence that base flow is positively affected by precipitation (or recharge), and that it varies inversely with drainage density. Carlston has also found that progressive increase in aridity results in a decrease in soil and vegetal cover which, in turn, greatly magnifies the range of drainage densities characteristic of semiarid regions. For example, the short-grass High Plains may have a local drainage density of only 0.25, whereas that of the White River badlands, a part of the short-grass area, may run into the hundreds.

[72] L. B. Leopold, 1962, The Vigil Network: Internat. Assoc. Sci. Hydrology, VII^e Ann., no. 2, June, p. 5–9, 3 figs.

[73] C. A. Cotton, 1964, the control of drainage density: New Zealand Jour. Geology and Geophysics, v. 7, p. 348–352.

[74] C. W. Carlston, 1963, Drainage density and streamflow: U.S. Geol. Survey Prof. Paper 422–C, p. C1–C8.

Modern and prior stream channels of the Riverine Plain, Australia

In recent studies of the Riverine Plain of southeastern Australia, S. A. Schumm found that the gradient of the modern Murrumbidgee River, where it crosses the plain, is about 0.7 foot per mile. In the same area the prior stream channels, aggraded and abandoned, exhibit gradients of about 1.5 feet per mile. The decrease in stream gradients, which has occurred since the prior streams were flowing, was apparently caused by a climatic change from semiarid to subhumid. The climatic change lead to increased runoff and to a decrease in the quantity of sand transported through the channel. The decrease in gradient was accomplished by a major increase in channel length, accompanied by a change in load from sand to silt and clay, and by development of a greatly increased meandering pattern. The sinuosity of the Murrumbidgee is about 2.1, whereas the sinuosity of the prior streams was about 1.1. These observations suggest that parallel river terraces of identical slope may be produced by streams of greatly differing sinuosity and gradient which are transporting very different types of sediments.

Fluvial processes

A catastrophic flood in December 1964 greatly modified the valley of Coffee Creek, in Trinity County, Calif. The creek, a high mountain stream in the Shasta National Forest, is fairly typical of numerous other streams of this region. Detailed mapping of erosional and depositional features on large-scale aerial photographs, by J. H. Stewart and V. C. LaMarche, Jr., shows that movement of a large volume of predominantly coarse alluvium was accompanied by destruction of vegetation, roads, buildings, and other structures, and by changes in the character and location of the stream channel. Such rather infrequent flood events seem to be mainly responsible for the geomorphic features of the flood plain and of the distribution and texture of the flood-plain and channel deposits.

Erosional history from geobotanical evidence

External features and internal growth characteristics of trees flanking a small, ephemeral stream channel in Red Canyon near the entrance to Bryce Canyon National Park, Utah, were used by V. C. LaMarche, Jr. (p. D83–D86), to decipher local erosional history. Channel degradation has totalled 10 feet in the past 800 years. Rapid channel incision about A.D. 1700 was apparently related to local change in base-level rather than to an erosional cycle of regional extent.

Geochronology

A search for long-lived trees useful in hydrologic, geologic, and geomorphologic research led last year to the discovery of three new localities of very old bristlecone pines. R. W. Russell, of the National Park Service's Bryce Canyon staff called the attention of G. G. Parker and V. C. LaMarche, Jr., to the oldest of these, which is on the Table Cliffs Plateau, across Paria Valley from Bryce Canyon National Park, Utah.

Parícutin volcano approaching stability

Kenneth Segerstrom (p. C93–C101) found in a study of the geomorphic history of Parícutin volcano that inner and outer slopes of the crater and cone have changed little since 1957. Except on steep slopes, devastated areas outside the immediate area of the cone and surrounding lava fields have recovered spectacularly, chiefly through revegetation.

Slope processes

S. A. Schumm has measured rates of creep on hillslopes of Cretaceous Mancos Shale in western Colorado, using identifiable rock fragments. The distances over which 110 such fragments moved in 7 years demonstrates that the rate of creep (V, in millimeters per year) is directly proportional to the sine of hillslope inclination (S) as follows: $V = 122 \sin S - 1.2$. The rates of movement measured in western Colorado, compared with measurements made elsewhere, indicate that rates of creep affected by frost action, in a region of low precipitation, are greater than rates of soil creep measured in a humid climate; but that they are lower than rates of talus creep and solifluction measured at high latitudes.

Paleoenvironment in northeastern Arizona

Deric O'Bryan and M. E. Cooley are using geomorphology, sedimentation, palynology, dendrochronology, archeology, and historical research in the study of late Recent sequences of alluviation, arroyo cutting, and terracing along parts of Chinle Wash and its tributaries, in northeastern Arizona. These sequences will be related to the effects of hydrogeologic and other environmental controls to reconstruct the local paleoenvironment. This should aid in the reconstruction of paleoenvironments in other drylands areas.

Late Recent alluvial deposits and terraces are widely distributed in the valleys and canyons of the Colorado Plateaus. They have been described locally by numerous authors and tentatively dated generally as having formed since 2,000 B.C. The alluvium consists mainly of two deposits; the older was deposited between about 2,000 (?) B.C. and A.D. 1100–1200, and

230-568 O-67—13

the younger was deposited after about 1300 and 1850, when the present arroyos began to form along many drainages. Locally, these two alluvial deposits form low alluvial terraces. Remains of prehistoric Pueblo Indian culture are common locally in the upper part of the older alluvial deposit. Sites at which Basketmaker III and Pueblo I (8th to 10th centuries) remains are buried in the alluvium, visited by Deric O'Bryan and M. E. Cooley, are stratigraphically as much as 25 feet below the top of the older alluvium. Pueblo II and III (11th to 13th centuries) remains either are buried in the upper few feet of the older alluvium or occur on the terraced surface cut from that unit.

An archaeological cave site on Walker Creek, in Arizona, was exposed by the present cutting of arroyos. Alluvial fill chokes the cave to a height of 33 feet. Archaeological remains of a Basketmaker III occupancy (8th century) form a stratum about 3 feet above the sandstone floor of the cave. A Pueblo II (11th century) occupation level rests on 7 feet of sterile(?) fill above the Basketmaker remains. An additional 23 feet of alluvium accumulated in the cave before the arroyo trenching began. This cave should be a key site for the application of the above techniques.

Piping and collapse structure

G. G. Parker's studies of erosion have focused attention on two processes, piping and collapse, to which geologists and geomorphologists had previously paid little attention. Piping is the natural development of subsurface drainage tubes (pipes) in relatively insoluble clastic materials such as clay, silt, sand, alluvium, volcanic ash, tuff, and in some consolidated rocks such as claystone, mudstone, shale, and sandstone. Collapse structure often occurs in conjunction with piping; it attacks several kinds of low-density detrital materials such as dry deposits of silt, loess, volcanic ash, and weathered arkose–materials having very loose packing and open fabric. The component grains are weakly bound together by thin cementing coatings or "rings" at their junctures with adjoining grains. Cements are commonly clay minerals; some of them are impure iron oxides. If these weak cements fail under stresses applied by newly built heavy structures, by traffic or earthquake vibrations, or by concentrations of water, resultant differential compaction, settlement, and often disastrous piping occur. Acting alone, or in concert with other processes, piping and collapse produce pseudokarst features duplicating rather faithfully typical karst features of limestone and dolomite terranes. The features are not so long lived, however, and likewise develop much more rapidly. In some dryland western valleys these erosion processes are the chief agent of destruction to alluvial valley fills.

PLANT ECOLOGY

Studies that compare plant cover with variations in available water and with differences in geology and geomorphic processes require consideration of the effects of marked changes in vegetation, some of which occur rapidly, over short periods, and some of which occur very slowly, over long periods. An understanding of the relations between plant distribution and environmental parameters may permit the prediction of variations in the environment from the study of vegetation.

Rainfall and plant growth in New Mexico

Larger numbers of plant species, and of individual plants, were observed in northwestern New Mexico following one season of heavy rain in 1965, as compared with the character of vegetation during the dry years of 1961 and 1962. This observation emphasizes that vegetation is dynamic and that related geologic and hydrologic studies must recognize this variable characteristic. In her geochemical studies of rocks, soils, and plants in San Juan County, N. Mex., H. L. Cannon found that perennial and annual species of *Atriplex* (salt-bush) were more abundant on Mancos Shale in 1965 than earlier, and that perennial species regenerated from seemingly dead crowns. Several species of *Eriogonum* (wild buckwheat) and *Senecio* (groundsel) were found that had not been recorded before. The sizes of grasses and the numbers of species increased; needlegrasses and wheatgrasses were dominant in places where only scattered plants occurred in 1961. Russian thistle, on the other hand, was predominant in the Chinle Valley west of the Chuska Mountains in 1961 and 1962, but was small and immature in the fall of 1965. Another year of high rainfall may markedly improve the Navajo Reservation rangelands.

Forest as an indicator of hydrologic conditions

Because mature forests, with old trees and well-formed soil horizons and humus, affect water resources and geomorphic processes in a manner different from that of plants cultivated by man, R. S. Sigafoos is studying the range of variability in deciduous forests near Washington, D.C. In areas of forest that is seemingly little disturbed, death of the once-prominent chestnut (around 1910), selective and clear cutting in the last 50 to 100 years, and fire have all modified the species content of the forests and led to marked changes in the form and size of the trees. The areal distribution of species seems to be related to areal differences in the hydrology, and it seems likely that variations in the distribution of ground water and in the flow of small streams might be predicted from a knowledge of the vegetation.

Rainfall and vegetation in Baja California

The close relationship between differences in rainfall regimes and differences in vegetation in Baja California suggests that analysis of vegetation alone has value in predicting regional desert vegetation. J. R. Hastings and R. M. Turner (r0544) have analyzed precipitation data now being collected by the Mexican Government. A close relationship exists between seasonal distribution and quantity of rainfall and the 6 vegetation provinces defined on the peninsula 30 years ago through interpretation of differences in vegetation.

Response of eastern trees to hydrologic conditions

Growth studies of eastern deciduous trees by R. L. Phipps illustrate the diversity of the responses of different species to hydrologic conditions. The number of earlywood cells of ring-porous species, such as the oaks, appears to reflect conditions of the previous growth season, whereas the size of these cells appears to reflect conditions of the current growth season (even prior to complete leaf expansion and full nutrient production). Earlywood cells of ring-porous species appear to have been cut off from the vascular cambium late in the previous growth season, or after it, whereas enlargement and differentiation of the cells occur early in the current growth season. Earlywood of ring-porous species also seems to have no counterpart in diffuse-porous species, such as the maples. Careful selection of trees and of species, and the analysis of number and size of earlywood cells in ring-porous species, may therefore permit the interpretation of variations in environmental parameters of a duration as short as a week.

Growth restrictions in trees

Interpretation of climate on the basis of tree-ring studies requires an understanding of growth behavior at several levels in the trees because of variations in growth in single trees at different levels. Restricted tree growth related to drought has a different three-dimensional shape than does restricted tree growth due to suppression by surrounding trees, and R. L. Phipps believes that it may be possible to distinguish the two types of growth restriction in eastern deciduous trees. Suppression by surrounding trees appears to result in gradual restriction of growth at all heights, during successive years. Growth during drought years commonly is not restricted at the crown positions in trees, however, because growth here occurs in the spring when soil moisture is high and does not limit growth. Growth in lower parts of trees, which occurs later, may be restricted because of decreased soil-moisture supplies. Restricted growth near the base of a tree, at the level usually sampled, may be the result of either suppression by surrounding trees or of drought. The cause may be inferred if growth at other heights is also examined, but false inferences may be drawn if only one level is studied.

GLACIOLOGY

Glacier variations have been measured for several centuries because it has long been realized that these variations may be very sensitive indicators of climatic change. However, the exact relation of glaciers to climate involves complications such as spatial variations in meterological parameters and glacier mass budgets, differing dynamic-response characteristics of the glaciers, and glacier surges (glacier fluctuations which are not related to climate). Glacier research has yielded new information on some of these complications, and new approaches have been devised to record glacier variations.

Mesoscale variations in climate and in mass budgets of glaciers

As a part of a program to determine the consistency of glacier behavior in a given region, recent changes in Klawatti Glacier, Wash., have been investigated by W. J. Campbell. This glacier has two lobes of about equal size, both flowing east and spanning about the same range in altitude. Yet in the period 1947–61, one lobe retreated markedly and decreased in thickness by an average of 8.3 meters, and the other lobe advanced and thickened by 5.8 m. This behavior cannot be explained in terms of a single, simple phenomenon such as a hypothetical "rise in a zone of maximum snowfall" or a change in storms. However, A. L. Rasmussen has computed a hypothetical distribution curve for the quantity, net budget/altitude, that approximately reproduces the known behavior of the two lobes. Thus the problem demonstrates the importance of mesoscale meteorological complications in determining glacier behavior.

Interpretations of fluctuations in glacier volume

In order to determine the validity of certain interpretations of glacier-remapping programs, M. F. Meier studied maps and other data on Nisqually, South Cascade, and Klawatti Glaciers, Wash. He demonstrated that (1) changes in thickness derived photogrammetrically cannot be used to determine ablation, other specific mass-budget quantities, or response characteristics, without concurrent measurements made on the glacier surface; (2) kinematic wave progression on glaciers such as Nisqually can be determined only if the time interval between maps is less than about 5 years; and (3) one cannot extrapolate climatic changes from maps of single glaciers without a statistical sampling of other glaciers or knowledge of the mesometeorological environment.

A remarkable glacier surge in Alaska

Any theory which relates glacier variations to climatic changes must also consider the problem of surging glaciers (also called sporadic or catastrophically advancing glaciers). In a special study of surging glaciers in Alaska, Austin Post has discovered that the Walsh Glacier began a surge in late 1960 or early 1961, after 40 years or more of virtual stagnation. A maximum movement of 10.1 kilometers occurred in the central portion of the glacier, as shown by aerial photographs of the displacement of surface features. This may be the greatest such displacement yet reported for a mountain glacier.

Computation of sequences of glacier variation

W. V. Tangborn has determined the net mass budget of South Cascade Glacier, Wash., for a 7-year period, using precipitation, runoff, and water-loss data; and has checked this calculated value with net mass budgets measured directly on the glacier. Having confirmed the technique, he has utilized longer term records of precipitation and streamflow in a larger Cascade River drainage basin to calculate glacier net budgets extending back in time for about 30 years. (See also discussion of South Cascade Glacier, in section "Geologic Applications of Remote Sensing.")

PERMAFROST

Rubble field near Monterey, Va.

W. E. Davies has studied a rubble field on Jacks Mountain near Monterey, Va. It is developed from sandstone of the Clinton (Rose Hill) Formation of Middle Silurian age, and it shows strong effects of frost action. Slabs as much as 2 feet on a side are turned on end in long curving rows. In addition, there is distinct gradation of size, with large slabs at the surface grading downward for 10 feet or more to small plates and chips. The coarse material is free of sand or silt, which are concentrated in the zone of smaller fragments a few feet above bedrock. A thick cover of lichens on the rocks indicates that the frost action is old. The frost-riven material is similar in development to that observed in Greenland near Thule, and the Jacks Mountain occurrence is probably relict from late Pleistocene conditions.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Carbon dioxide determination in carbonate rocks by acid-base titration

Acid-base titration methods for the rapid determination of carbon dioxide in limestone and dolomite were developed by F. S. Grimaldi, Leonard Shapiro, and Marian Schnepfe (p. B186–B188). The method is based on the dissolution of a sample in an excess of standard acid followed by back titration with standard base. Difficulties arising from the solubility of some silicates are minimized by conducting the acid decomposition under mild condtions. In one procedure, this is realized by overnight digestion of the sample with acid at room temperature, and in another procedure, the sample is boiled for a short time with a predetermined limited amount of excess acid.

Rapid analysis of rocks and minerals from a single solution

Leonard Shapiro modified the rapid rock-analysis procedure so that the total elapsed time for completing analyses for 10 elements on a few samples is about 3 hours. Fifty samples can be analyzed easily by one analyst in a week. The determinations are made on a single solution after a lithium metaborate fusion of the sample. CaO, MgO, K_2O, Na_2O, and MnO are now determined by atomic absorption; SiO_2, Al_2O_3, Fe_2O_3, TiO_2, and P_2O_5 are determined spectrophotometrically as before. Sample sizes range from 20 to 100 milligrams.

Sulfur in volcanic glass

A published procedure for determining microgram quantities of total sulfur in rocks was modified by B. L. Ingram and used to determine total sulfur in a volcanic glass. According to the published procedure, sulfur is released by heating the sample with vanadium pentoxide in a tube furnace at 950°C in a nitrogen atmosphere. The gas is swept over copper metal heated at 950°C into a solution of sodium tetrachloromercurate; the sulfur dioxide is absorbed in this solution and determined colorimetrically with pararosaniline. Very little of the sulfur present is expelled from glasses using this procedure. The problem was solved by sintering the glass with magnesium oxide at 1,000°C prior to the addition of vanadium pentoxide. Magnesium oxide can be freed completely from sulfur by prior ignitions at 1,275°C.

An improved micropycnometer

A micropycnometer for the microdetermination of specific gravity of powdered minerals was designed by Irving May and John Marinenko. The novel features of the pycnometer are the reproducible closure with a steel ball and the delicate means of detecting the end of the evaporation of excess displacement liquid. Filling of the pycnometer can be achieved with a reproducibility of 0.0001 milliliter, a necessary condition for limiting errors to less than 0.1 in specific gravity. Tetrachloroethylene is used as the displacement liquid because of its desirable rate of evaporation, which allows excellent control of the evaporation step; its high specific gravity of 1.6 reduces the effect of small weighing errors. Results on 8- to 10-milligram samples of minerals having specific gravities between 2.6 and 4.5 agree satisfactorily with those obtained by standard macrotechniques.

Magnesium nitrate as a salting agent

Magnesium nitrate was found by K. W. Edwards and M. S. Rickard to be an effective salting agent in the extraction of uranium into ethyl acetate. A 3.5-molar magnesium nitrate solution which is 1 molar in nitric acid was found to extract uranium more effectively than saturated aluminum nitrate, 1 molar in nitric acid. Magnesium nitrate was also found to have a lower uranium blank than specially purified aluminum nitrate.

Uranium, radium, and thorium analyses by gamma-ray spectrometry

A gamma-ray spectrometric procedure for a direct determination of uranium and an indirect determination of thorium and equivalent radium in whole-rock samples was developed by C. M. Bunker and C. A. Bush (p. B176–B181). Uranium is determined from the uranium-235 content, equivalent radium from the lead-212 content, and thorium from the lead-212 content. One-to-two-pound samples are counted for a maximum data accumulation time of 1,000 minutes, with a 200-channel spectrometer system including a 4 × 5-inch sodium iodide crystal. Analysis of the data is made by a combination of graphical and mathematical techniques. Detection limits are 1.5 parts per million for uranium and 1 ppm each for thorium and equivalent radium.

In-situ activation analysis with a portable positive-ion accelerator

A feasibility study has been made by F. E. Senftle, A. F. Hoyte, and Prudencio Martinez to operate by remote control an unshielded portable positive-ion accelerator-type neutron source to induce activities in the ground rock by "in situ" neutron irradiation. Selective activation techniques make it possible to detect some 30 or more elements by irradiating the ground for periods of a few minutes with either 3- or 14-million-electron-volt neutrons. The depth of penetration of neutrons, the effect of water content of the soil on neutron moderation, gamma-ray attenuation in the soil, and other problems are considered.

The analysis shows that, in exploration for most elements of economic interest, the reaction $H^2(d,n)He^3$ yielding ≈3-Mev neutrons is most practical to produce a relatively uniform flux of neutrons of less than 1 thousand electron volts to a depth of 19–20 inches. Irradiation with high-energy neutrons (≈14 Mev) can also be used and may be better suited for certain problems. However, due to higher background and lower sensitivity for the heavy elements, fast neutron activation is not recommended for general exploration use.

Determination of cesium, chromium, hafnium, and tantalum by activation analysis

Using the National Reactor Laboratory reactor, Paul Greenland has developed an activation method for the simultaneous determination of cesium, chromium, hafnium, and tantalum in silicates. A 100-milligram sample is irradiated for 8 hours in a neutron flux of 5×10^{12} n/cm²/sec. After a 10-day delay period to permit the decay of short-lived activities, the sample is fused with sodium peroxide in the presence of carriers for Hf and Ta, and the fusion cake is leached with water. Cs and Cr are determined by direct counting of the leach solution using a NaI(Tl) crystal and a 256-channel analyzer to resolve the complex gamma spectrum. The precipitate from the leaching is dissolved, rare-earth activities are scavenged with a lanthanum fluoride precipitation, and the Hf and Ta activities in the filtrate are purified by ion exchange prior to gamma counting. Detection limits are about 0.01 part per million for Cs, Hf, and Ta while that for Cr depends markedly on the sample matrix; these limits may be easily improved with the use of larger samples and (or) longer irradiation times. The procedure is presently being used to study trace-element fractionation during magmatic crystallization, in collaboration with David Gottfried, and will soon be used to examine trace-element volatilization in tektites.

Determination of silver by atomic absorption spectrophotometry

Claude Huffman, Jr., J. D. Mensik, and L. F. Rader, Jr., have developed a rapid and precise atomic-absorption spectrophotometric method for the determination of silver in mineralized rocks (p. B189–B191). The procedure involves digesting the sample in nitric acid, centrifuging the diluted solution, and atomizing it into an atomic-absorption spectrophotometer for measurement of silver at a wavelength of 3,284 A. Silver content ranging from 1 part per million to about 9,000 ppm can be determined without preliminary separation, even when high concentrations of other elements are present.

OPTICAL SPECTROSCOPY

Determination of mercury

The use of mercury-halo methods as a guide to the location of sulfide ore deposits has led to increased interest in the geochemistry of mercury and has fostered a need for better methods for the determination of trace amounts of mercury in sulfide minerals. To improve the reliability of existing analytical methods for determining traces of mercury in sulfide minerals, J. I. Dinnin and H. W. Worthing (p. C220–C223) studied its chemical and spectrochemical determination. In a spectrochemical method developed by Worthing, mercury is volatilized from a deep crater using a short exposure time and a relatively large sample, with a resulting detection limit of 5 parts per million in a 50-milligram sample. In a chemical method developed by Dinnin, mercury is volatized in a Penfield tube and the separated mercury dissolved and determined colorimetrically with dithizone. One tenth of a part per million of mercury in a 1-gram sample may be detected by this means.

Minor elements in apatites

The minor-element content of apatite is important in studies of igneous differentiation and of marine and biological precipitation. It thus becomes of interest to obtain quantitative data on many of the elements which are substituents in this mineral. Because of the large number of elements (29) in question, emission spectrochemical analysis was favored as a method of approach. The strong calcium spectral background, however, presents a special problem. C. L. Waring and N. M. Conklin (p. C228–C230) completed a procedure applicable to this special case. In the procedure, 10 milligrams of the powdered sample is mixed with 5 mg of GeO_2 and 20 mg of graphite and packed into the crater of graphite electrode. The sample is burned to completion in a 15-ampere d-c arc for 130 seconds. Germanium is used as a buffer and internal standard. Calibration standards are prepared for 29 elements using spectroscopically pure tricalcium phosphate as a base. The elements are added as oxides to make a concentration series of standards from 0.5 to 0.0001 percent.

Direct-reading spectrochemical analyses

In direct-reading spectrometry the photographic plate is replaced by photomultiplier tubes as a means of recording the intensity of selected spectral lines. Though instrumentally much more complex than photographic recording and much more limited in the number of spectral lines that can be recorded simultaneously, direct reading instrumentation has a number of marked advantages for analyzing large numbers of samples. Moments after an "exposure" for a sample is completed, calculation of the analytical results can be completed and displayed, printed out, or recorded on tape. The form of output may be selected for direct computer handling of the data for subsequent studies. This latter feature is of particular importance to a planned geochemical-census program requiring many spectrochemical analyses.

In order to meet anticipated analytical requirements the Denver spectrochemical laboratory of the U.S. Geological Survey, under the direction of A. T. Myers, has completed the installation and testing of a direct-reading spectrometer. Forty elements, selected to meet the requirements of the geochemical program, are determined simultaneously. The readout system records the data directly in terms of element concentration. Provisions have been made in the readout system for convenient utilization of the data in various forms, as required by the geochemical-census group, for automatic computation.

The only operations that must be carried out in an analysis with this equipment are preparing and arcing the sample; the remaining steps of the analysis are automatic. Thus the very tedious steps of photometry, interpretation of the spectra, calculation, and recording of results are completed in the time it takes the operator to place the next sample electrode in position in the arc chamber.

X-RAY FLUORESCENCE ANALYSIS

Dilution-addition techniques

Frank Cuttitta and H. J. Rose are continuing studies of solution methods for micro-X-ray fluorescence analysis. An addition technique was found useful for determining microgram amounts of Br in brines and of Zn in opal glass. The lower limit of detection is about 10 micrograms for each element. In the procedure, a known amount of the element sought is added to the sample, readings being taken before and after adding it. The method is like a recovery experiment in reverse. If the working curve is linear, simple arithmetic evaluation of the original concentration is possible. This, however, assumes that matrix interferences exert the same multiplicative effect upon the total concentration after addition as upon the original concentration of the element sought.

ELECTRON-PROBE ANALYSIS

Electron-probe studies of sanidine

A number of single crystals of sanidine digested in a bath of KCl at 800°C for several days were examined by C. W. Mead for J. J. Papike. The probe analysis was made to check both the homogeneity of the grains and the extent of replacement of Na by K. The analysis was done by (1) spectrometer traces, (2) spectrometer scans, (3) point-by-point counts while a spectrometer was positioned for a given element, and (4) oscilloscope display of X-rays for a given element. The crystals were found to be homogeneous on a micron scale, and it was found that most, if not all, of the Na had been replaced by K. Ca, Sr, Ba, Fe, and Cl were looked for but not found.

Electron-probe study of weathered surfaces

Two basalt samples were analyzed by C. W. Mead to determine compositional variations of weathered basalt surfaces. Two weathered bands were noted on the periphery of both samples, and a comparison was made with the inner matrix. Fe and Ti were found to be highest in the inner weathered band and Si highest in the matrix. These observations were made within 10 microns of the surface of the sample.

Electron-probe standards

The possible use of fused materials for probe standards was investigated by H. J. Rose, who prepared a number of melts containing various concentrations of the standards G-1 and W-1 in lithium tetraborate. Fragments of the glassy beads formed by the fusion were then mounted in the usual way for probe analysis. Indications are that such melts make good standards. However, a heavy carbon coating, a fairly low accelerating voltage, and a short counting interval are necessary to prevent the beam from drilling a hole in the sample.

ELECTRON MICROSCOPY

Scanning electron microscopy

In the scanning electron microscope, a finely focused beam of electrons of approximately 500 A in diameter is accelerated by a voltage of 15 kilovolts and focused by magnetic lenses onto a sample at an angle of 45°. Deflection coils sweep the beam over the area of interest in a scanning sequence, "kicking out" secondary low-energy electrons from the sample surface. These electrons are collected on a scintillation counter whose light output is detected by a photomultiplier tube. The output from the tube is converted to a voltage, amplified, and used to control the brightness of a cathode-ray tube, in synchronization with the primary beam scanned. An image of the surface topography is presented on the screen and is photographed with a 35-mm camera. The area scanned can be varied from several square microns to several square millimeters, allowing useful magnifications from × 40,000 to × 100 with unusual depth of field. E. J. Dwornik (p. D209–D213) obtained micrographs of a variety of samples of geologic interest, including microfossils, glauconitic clay, obsidian fracture surfaces, airborne dust particles, metallic spherules, and fine grained minerals.

ANALYSIS OF WATER

Pesticides and organic acids

The characteristics of organic acids present in colored surface waters have been examined by W. L. Lamar and D. F. Goerlitz (r0380) by use of gas, column, and paper chromatography and by infrared spectroscopy. Organic acids were recovered from water by continuous extraction with n-butanol or by vacuum evaporation at 50°C. The effective chain-length criteria for both polar and nonpolar columns were used to identify the esterified derivatives of the volatile acids. Thirteen volatile carboxylic acids were identified, of about 30 found. Most of the total acids recovered were nonvolatile and could not be made volatile for gas-chromatographic analysis. Infrared examination of column-chromatographic fractions indicated that these nonvolatile substances are primarily polymeric hydroxy carboxylic acids having aromatic and olefinic unsaturation. Some may result from polymerization in aqueous solution. The isolated acids are soluble in polar solvents such as acetone and alcohol, slightly soluble in ethyl ether, and insoluble in hexane, methylene chloride, and benzene. Examination of the solid acids by X-ray diffraction showed them to be noncrystalline, and elemental analyses of the sodium-fusion products proved the absence of nitrogen, sulfur, and halogens.

W. L. Lamar, D. F. Goerlitz, and L. M. Law developed improved gas-chromatographic columns which facilitate the identification and measurement of submicrogram amounts of 13 common chlorinated and phosphorothioate insecticides in as little as 1 liter of a water sample by electron-capture gas chromatography. The improved columns, prepared by the "frontal analysis" technique, suppress decomposition of the insecticides during analysis, and thus permit the detection of as little as 10 parts per trillion, or less, of aldrin, DDT, DDD, dieldrin, endrin, heptachlor, heptachlor epoxide, and lindane; as little as 50 ppt of methyl parathion and parathion; as little as 100 ppt of chlordane and malathion; and as little as 200 ppt of methoxychlor. Acid-washed Chromosorb G of 60- to 70-mesh size is first coated with Carbowax 20M and then with one of two liquid substrates (DC 200 silicone fluid, 12,500 centistokes; or QF–1 fluorosilicone, also known as FS 1265). Because of the high sensitivity of the method, the laboratory is a prime source of contamination, and corrective measures for interference resulting from contamination in the laboratory are necessary.

Methods for determining phenoxy acid herbicides by both electron capture and microcoulometric gas chromatography have been developed by D. F. Goerlitz and W. L. Lamar. One-liter samples are acidified to pH 2 and extracted with ethyl ether, and the extracts are then concentrated and esterified. Those with little or no color are esterified with boron trifluoride-methanol reagent and analyzed by electron-capture gas chromatography. Colored extracts and those containing significant amounts of extraneous material are esterified with diazomethane and analyzed by microcoulometric-titration gas chromatography. Under optimum conditions, the lower detection limit by either method is about 50 to 100 ppt for 2,4-D, and 10 to 20 ppt for 2,4,5-T and Silvex. The determination of submicrogram amounts of these materials is difficult in samples which contain interfering contaminants, and cleanup techniques are usually necessary.

The insecticide Sevin ®, 1-naphthyl-N-methylcarbamate, decomposes into 1-naphthol and methyl isocyanate at the temperature required for its vaporization in the injection chamber of a gas chromatograph. Moreover, the extent of the decomposition is influenced by both the carrier gas used and the sample matrix. Lloyd Kahn has demonstrated that concentrations of this material can nevertheless be determined from measurements of the observed peak heights of the 1-naphthol formed and of the undecomposed Sevin ®. The following relationship is used:

$$W_{7u}=W_7-(W_\alpha+0.395\ W_\alpha),$$

where W_{7u} is the weight of Sevin ® in the sample; W_7 is the weight of undecomposed Sevin ®, determined from an analytical curve prepared by injecting known amounts of the compound; and W_α is the weight of 1-naphthol formed by the decomposition of Sevin ® during the analysis, determined from an analytical curve previously prepared by injecting known amounts of 1-naphthol. The factor 0.395 is the ratio of the molecular weights of methyl isocyanate and 1-naphthol.

R. L. Wershaw and M. C. Goldberg calculated the apparent ionization constants of 2,4-D, at several concentrations, from conductance measurements obtained with a newly designed high-precision conductivity bridge. Two systems of equations were evaluated in order to determine a reliable and versatile method for converting conductance data into ionization constants. Applying the Onsager-Fuoss-Kraus equation for weak electrolytes, and using a method of successive approximations, they were able mathematically to determine satisfactory values for equivalent ion conductances at infinite dilution. From these data they estimated the aqueous solubility of 2,4-D.

Sample collection and storage

K. V. Slack and G. G. Ehrlich found that bacterial activity over a 2-week period changes both the pH and the total alkalinity of water samples which contain appreciable suspended organic matter. Membrane filtration of the samples at the time of collection, or the addition of chloroform as a preservative, minimize the extent of these changes.

A readily portable, all-plastic pressure filter was developed by G. F. Scarbro and M. W. Skougstad for the field and laboratory filtration of water samples. Several liters of sample may be filtered rapidly with a minimum risk of chemical alteration or contamination of the sample with respect to inorganic solutes. The filter uses standard 10.2-centimeter-diameter filters of any desired type. The micropore membrane filter is probably best for most purposes.

Determination of aluminum concentration

A fluorometric method for determining aluminum concentrations of 0.002 parts per million and greater in water was developed by D. E. Donaldson (p. D258–D262). Pontachrome Blue Black R is the recommended fluorescent reagent because it is not as susceptible to interference by fluoride and phosphate as are some other reagents. Fairly rigorous control of several analytical operations and conditions, such as reagent concentrations, pH, reaction time, temperature, and so forth, is necessary to ensure reproducible results.

Manual of analytical methods

A manual of methods for determining several cations (including calcium, copper, lithium, magnesium, manganese, potassium, sodium, strontium and zinc) in atmospheric precipitation, fresh waters, and brines has been prepared by M. J. Fishman and S. C. Downs. Methods have also been developed for the determination of trace amounts of several heavy metals such as manganese, copper, lead, nickel, and cobalt, by first complexing the metal ion with ammonium pyrrolidine dithiocarbamate at a controlled pH and then extracting the complex into methyl-n-amyl ketone. Under optimum conditions it is possible to determine as little as 1 part per billion of the element by this procedure.

HYDROLOGIC MEASUREMENTS AND INSTRUMENTATION

Digital recorders have been installed by the U.S. Geological Survey at more than 3,800 sites. Stage is being recorded at 3,000 of these sites, and a variety of other hydrologic parameters are being recorded at other sites. The number of recorder installations will be increased to approximately 4,500 within the next year.

Much additional progress has been made in adapting the digital recorder to recording a wider variety of hydrologic parameters. Sensors and systems have been developed which make it possible to sense and record most desired variables.

Applications of the digital-punch gage

J. E. McCall has adapted an automatic digital water-stage recorder to collection of data for determination of the following parameters: (1) daily mean discharge, (2) outflow from a pond at 5-minute intervals, (3) inflow to the pond at 15-minute intervals, and (4) average evaporation rates from the pond surface during hot, dry periods of several days' duration. This pond gage and digital recorder, in combination, offer a highly accurate technique for obtaining a complete storm hydrograph in situations where it is difficult to measure flash runoff by conventional methods.

H. O. Wires reports that a digital lister-adder has been designed and built in prototype. It is intended for general use in field offices, for speeding selected short-period tabulation or analysis of records.

The tipping-bucket rain gage has been adapted for use with the digital recorder by G. F. Smoot and R. H. Billings. Each tenth of an inch of rainfall advances the digital recorder one division. A lost-motion coupling is provided to store any tips of the bucket that may occur during the lockup of the punch.

G. F. Smoot, D. I. Cahal, and K. D. Medina report the development and installation of an instrument for recording digitally the position of gates on Greenup Dam, on the Ohio River. The record of gate positions will be used, along with pool and downstream elevations, for computing discharge of the Ohio River at this site.

Application of digital computer to hydrologic problems

A. I. Johnson and S. M. Lang report the development of an automatic data-processing system utilizing 6 standard punchcards and 1 microfilm aperture-type punchcard, devised for the storage and retrieval of sample-analysis data obtained in the U.S. Geological Survey's hydrologic laboratory. An automated-aperture camera has been evaluated for a wide variety of applications for the microfilm storage of illustrative information.

C. O. Morgan and J. M. McNellis have developed a program for the digital computer to arrange quality-of-water data into printed tables of the type usually published in ground-water reports. The program provides facility in arranging the tables and produces the tables in a form directly reproducible for publication, thereby reducing the amount of proofreading and eliminating the need of typing. In addition, operational programs have been written for arranging quality-of-water data directly into Piper and Stiff diagrams. A program that plots both quality-of-water and well-schedule data in the form of scaled maps is being used to aid interpretation of the data. Another computer program calculates latitude and longitude coordinates from General Land Office locations, to an accuracy within a few seconds of the measured coordinates. Water-level data are tabulated by a computer program in the forms published by the U.S. Geological Survey. Hydrographs are printed by the computer to various time and distance scales. A program for abbreviated well-log data has been designed primarily to plot data on maps; another operational program assists in proofreading.

Analysis of calibration of Price current meters

G. F. Smoot and R. W. Carter have made a statistical analysis of the calibration of Price current meters, and a study of the effects of worn or damaged parts on calibration. They defined the accuracy of calibration and found that a common rating of all of one type of meter made by a single manufacturer is comparable in accuracy to that of the calibrations of individual meters.

Measurement of discharge

F. A. Kilpatrick reports that numerous field tests have indicated the feasibility of measuring stream discharge by dye-dilution methods. The success of field tests involving the measurement of unsteady flow in canals suggests the application of this method to the complete measurement of flash-flood runoff.

Kilpatrick also reports on experimental artificial stream-gaging controls installed in the Midwest. Trapezoidal, supercritical flow flumes have proved successful in measuring rock- and debris-laden flows, whereas a loose, crushed-rock control has not.

An analysis made by T. H. Thompson of pulsating-flow characteristics indicates that photographic instrumentation to record rapidly fluctuating stage will not provide enough information to compute the discharge. The dye-dilution method apears to be the only technique now feasible for determining discharge in channels carrying pulsating flow.

Measurement of velocity of streamflow

B. J. Frederick made a field comparison of results obtained with the standard Price low-velocity meter and the Deep Water Isotopic Current Analyser. The two methods showed good agreement. The current analyzer is commercial equipment. It was designed to measure the average velocity of a radioactive particle (iodine-131) over a 25-centimeter path, at any specific depth down to 600 feet, and it indicates the average direction of flow to the nearest 15°. Because it measures low velocities (0.01 to 2.0 feet per second) and has no moving parts, it may prove useful in the problem of measuring pulsating currents.

Stepwise method of drilling

A method of step drilling was devised by B. F. Joyner, Horace Sutcliffe, and H. N. Flippo. About 50 feet of open hole is drilled into the formation with each step, using a 4-inch casing which is driven below the larger casing and which is equipped with a drive shoe that excludes water from above. After each drilling step, during which formation samples are taken at 10-foot intervals, the well is pumped before the water level is recorded. The 4-inch casing is then pulled, and the hole is reamed and the large casing driven before a new step is begun. This method is time consuming, but it is producing excellent results in delineating the producing zones of the Hawthorn, Tampa, and Suwannee Formations of Florida.

Modification of sledgehammer method of seismic surveying

J. H. Criner (p. B104–B107) describes the use of firecracker explosions in a modification of the sledgehammer method of seismic surveying. Using a single geophone to record the arrival of the shock waves resulted in a substantial economy of time and effort. Criner found that use of M-80 salutes for producing the shock waves is both safe and inexpensive.

Geophysical logging

W. S. Keys has developed and field tested a 500-foot miniature geophysical logger which makes a total of 12 different types of logs. An oil-field impeller flowmeter, added to it, will be used to make continuous and stationary velocity logs. Keys has also developed a logging system to measure sonic velocity. Sonic logs provide porosity measurement and serve to locate fracture zones. A multiple electrode under development will allow measurement of interstitial-fluid resistivity.

E. R. Bullard has developed a system for recording radiation logs on magnetic tape.

Determination of specific yield

In research on specific yield, R. C. Prill and A. I. Johnson found that temperature, method of sample preparation, and design of equipment have considerable effect on data obtained from moisture-tension tests. The studies, designed to evaluate use of these tests for estimating specific yield, also indicated that data obtained by the moisture-tension technique can be correlated well with data obtained by long-column drainage and centrifuge scale-modeling techniques.

Extraction of fluid from compact sediment

F. T. Manheim reports (p. C256–C261) that squeezing compact sediment at pressures from 3,000 to 9,000 pounds per square inch with a squeezer based on Kriukov designs does not appreciably affect the composition of extracted waters when proper precautions are observed. A 2-gram sample of relatively compact sediment from most samples of core materials from Recent to Paleocene sediments is completed in 3 minutes.

Experimental flow of pesticide solution through sand

J. B. Robertson and Lloyd Kahn studied the penetration of aldrin formulations through quartz columns. They found that the distribution of aldrin through the column profile appears to be established during the passage of the initial liter of water through the column, and that the total quantity of aldrin transported through the column in the stream of effluent water depends on the constitution of the formulation applied.

Use of aircraft in measurement of evapotranspiration

H. E. Skibitzke, R. L. Howell, Ray Lafferty, Jr., R. C. Rote, and associates have developed and successfully tested equipment and techniques for measuring continuously, from an aircraft in flight, both the amount of water vapor in the air and its direction of motion. Relative-humidity and temperature sensors, housed in a streamlined metal tube, are mounted on the wingstrut of a light aircraft, outboard from the influence of propwash. Mounted in the aircraft are accelerometers which define the aircraft acceleration with respect to its x, y, and z axes. The data from sensors and accelerometers are continuously transmitted to a modified M–33 military radar unit, which continuously tracks and records the position of the aircraft. The aircraft is flown at relatively low levels. Thus, the technique for measuring the evapotranspiration from a stand of phreatophytes requires flying the aircraft just above treetop level, on traverses that will afford suitable coverage of the stand of plants.

Hydrologic manual for the layman

T. J. Buchanan, Allen Sinnott, and P. W. Anderson (r0894) have prepared a manual entitled "Hydrologic Tools and Techniques for the Layman," as an aid to members of various citizens groups in drought-stricken New Jersey who have become interested in collecting hydrologic data themselves. The report gives instructions for collecting information on stream stages, ground-water levels, and some water-quality parameters, and contains plans for weirs and flumes to be used in measuring streamflow.

Statistical methods and inference

Prompted by the need of the hydrologist for methods to handle multivariate techniques, N. C. Matalas and B. S. Reiber investigated the underlying structure of factor analysis to ascertain the applicability of the method to hydrologic studies. They found that factor analysis is technically underdeveloped. Objective criteria are not available for interpretation of the results, and therefore two such analyses cannot be compared. Because of the subjective nature of factor analysis, this technique cannot be used as a total replacement for regression techniques.

TOPOGRAPHIC SURVEYS AND MAPPING

MAPPING ACCOMPLISHMENTS

Objectives of 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 Map Series covering the United States and other areas under the sovereignty of the United States of America. The individual series, at various scales, constitute a fundamental part of the basic data needed to inventory, develop, and manage the natural resources of the country. Other Division functions include the production of special maps and research and development in techniques and instrumentation

In addition to the maps described below, the Topographic Division prepares shaded-relief maps, United States base maps, special maps, and also a few planimetric maps.

Procedures for obtaining copies of the maps and map products of the Survey are given in the section "How to Order Geological Survey Publications."

Series and scales

All topographic surveys, except those in Alaska, conform to standards of accuracy and content required for publication at the scale of 1:24,000. Initial publication scale may be either 1:24,000 or 1:62,500, depending on the need. If 1:62,500-scale maps are published initially, the 1:24,000-scale surveys, in the form of photogrammetric compilation sheets, are available as advance prints and for future publication at the larger scale. For Alaskan maps, the publication scale is 1:63,360 or "inch-to-the mile."

Coverage of the Nation

Standard quadrangle map coverage at scales of 1:24,000, 1:62,500, 1:63,360 (Alaska only), and 1:20,000 (Puerto Rico only) is available for approximately 73 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands, Guam, and American Samoa (fig. 7). Included in this coverage is about 8 percent of the total area which is now available at these scales only as advance prints.

A total of 1,370 maps, published during fiscal year 1966, covers unmapped areas equivalent to 3 percent of the area of the 50 States and of the islands referred to above. In addition, 336 new maps at the scale of 1:24,000, equivalent to approximately 1 percent of the total area, were published to replace 15-minute quadrangle maps (scale 1:62,500) which do not meet present needs. For the extent and location of map coverage, see figure 8.

Map revision and maintenance

Map revision is necessary to show changes in manmade features, such as new roads, buildings, and reservoirs, and changes in the shape of the terrain. During fiscal year 1966, 145 standard quadrangle maps of the 7½-minute series were revised. Most of these newly revised maps were in urban areas or in the States completely mapped in the 7½-minute series. Because a large percentage of the National Topographic Program was devoted to new mapping, the backlog of maps needing revision continued to grow in 1966 and is now estimated to be about 7,000 maps. (See fig. 9.)

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 map. In fiscal year 1966 the Topographic Division adopted a policy of map revision defining three kinds of revision which will be applied, as needed, to standard quadrangle maps: (1) complete revision to improve the basic accuracy by recompiling a part or all of the map; (2) standard revision to make all additions and deletions to the existing map materials, with no improvement in accuracy of the map; or (3) limited revision to update only certain features or portions of the map.

About 1,450 standard quadrangle maps were reprinted in fiscal year 1966 to replenish stocks.

1:250,000-scale series

The 48 conterminous States and Hawaii are 99 percent covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service. 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 U.S. Geological Survey prepared and published a reconnaissance series for Alaska at the 1:250,000 scale, and is now replacing these maps with an improved series based on larger scale source material and on photogrammetric compilations. Figure 10 shows coverage of the 50 States, Puerto Rico, and the Virgin Islands by 1:250,000-scale maps, and the work in progress.

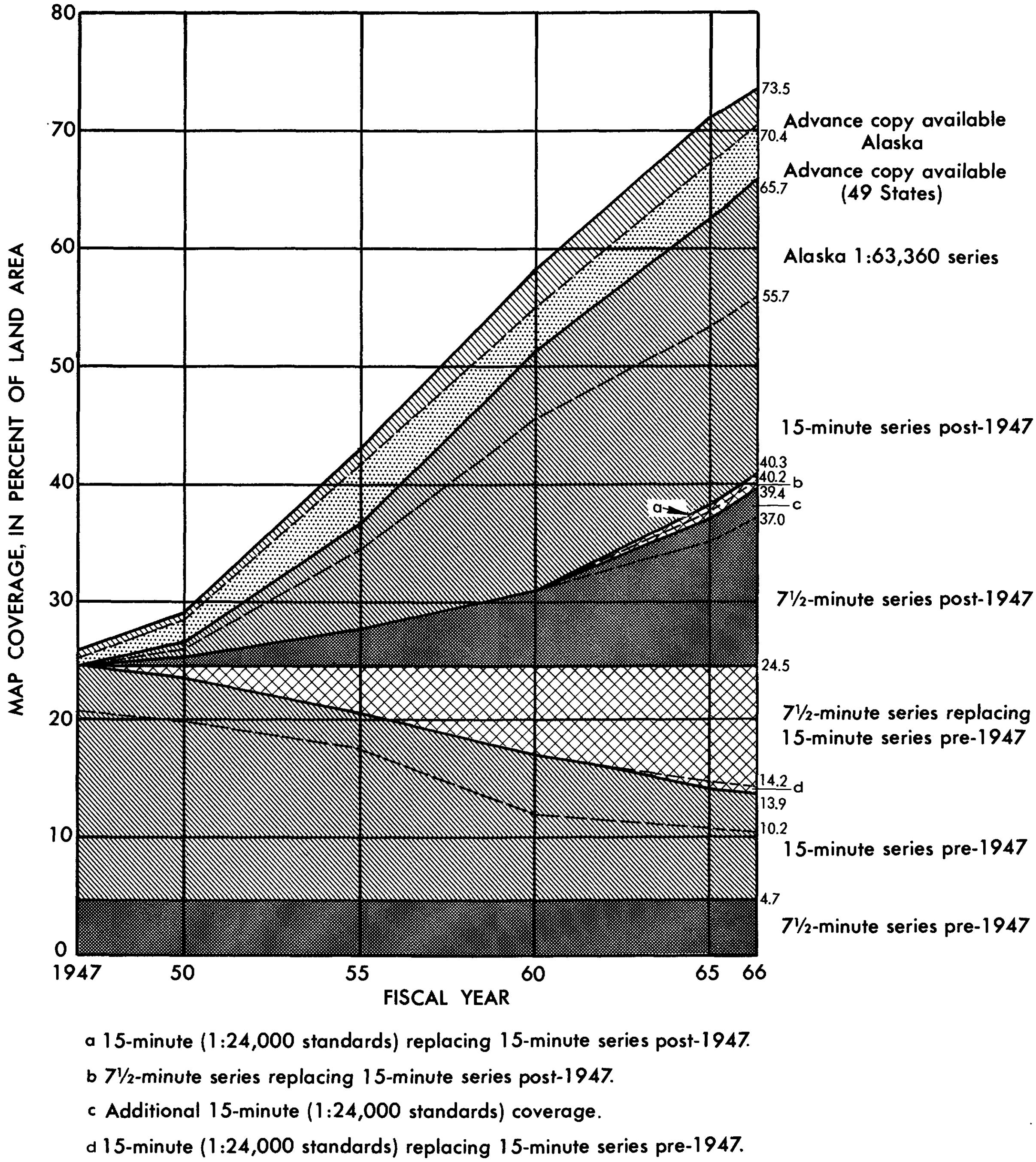

FIGURE 7.—Progress of 7½- and 15-minute quadrangle topographic mapping in the 50 States, Puerto Rico, and the Virgin Islands.

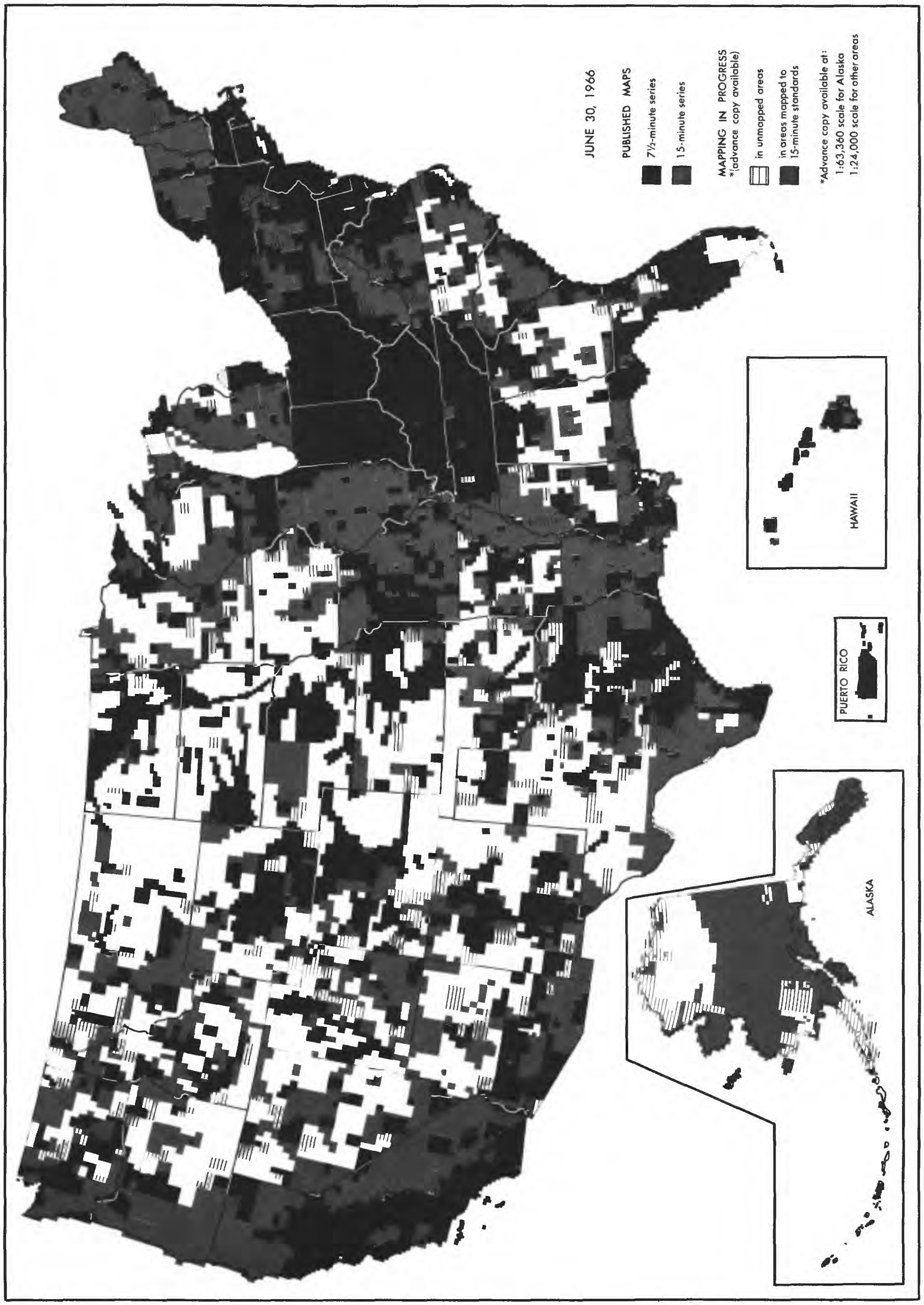

FIGURE 8.—Status of 7½- and 15-minute quadrangle topographic mapping.

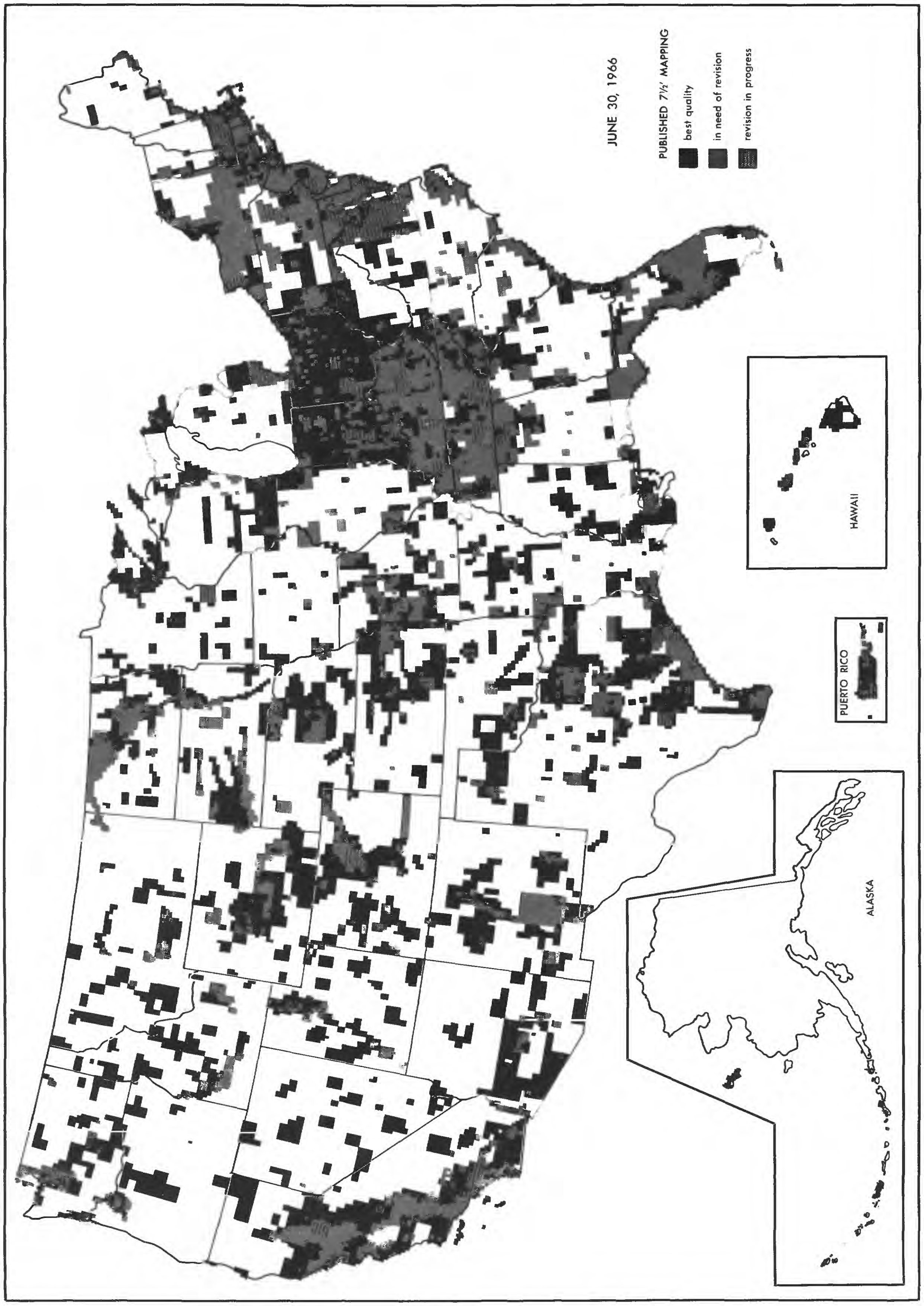

FIGURE 9.—Status of revision of large-scale topographic mapping.

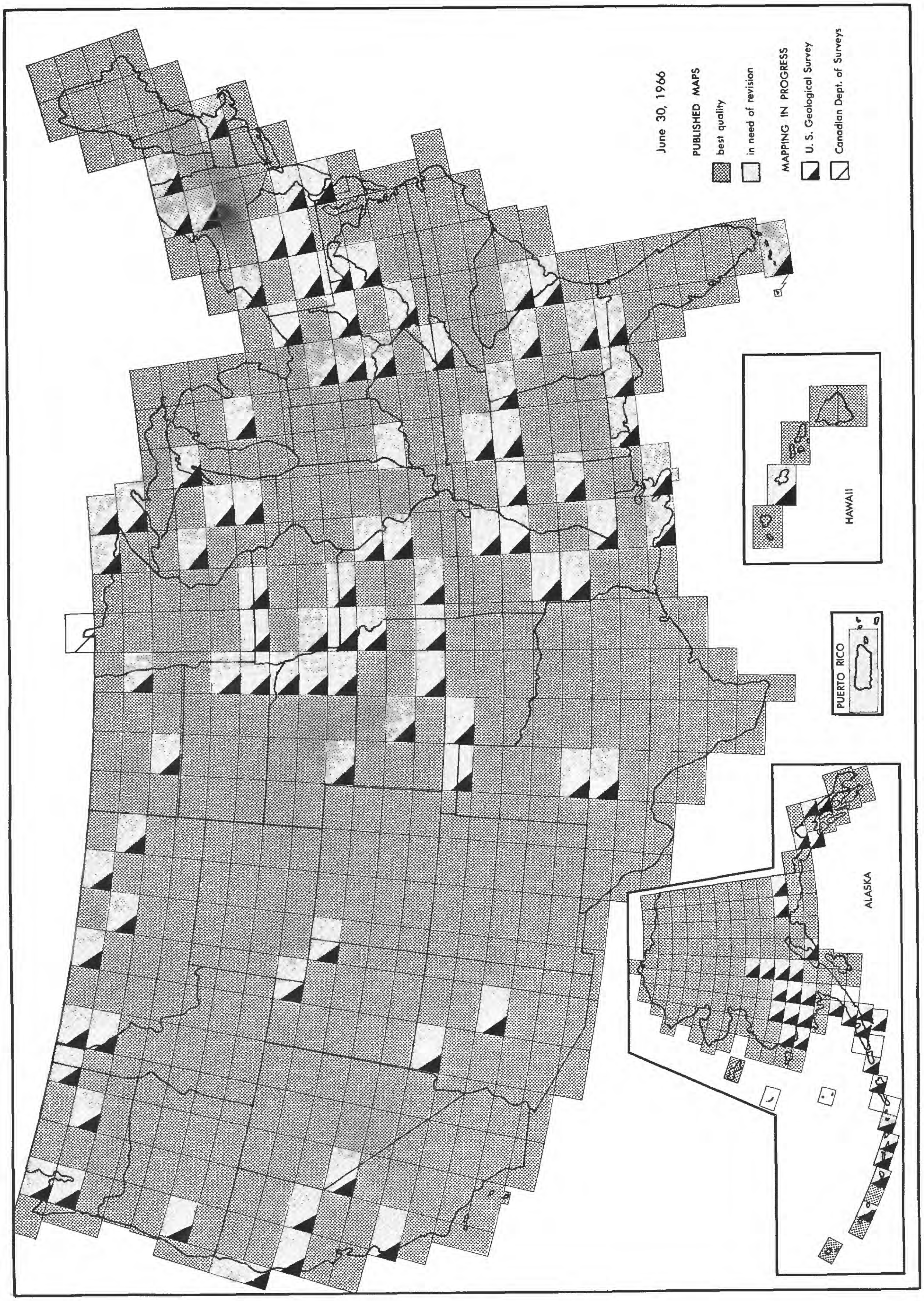

FIGURE 10.—Status of 1:250,000-scale topographic mapping.

State maps

State maps are published at the scales of 1:500,000 and 1:1,000,000 for all States except Alaska and Hawaii. Maps of Alaska are published at scales of 1:1,584,000 and 1:2,500,000. Hawaii is not yet covered by a State map.

The series of State maps, compiled according to modern standards, now contains 32 maps covering 36 States and the District of Columbia. All these maps are published in planimetric editions; contour and shaded-relief editions are also available for most of them. Two of the maps, California and New Mexico, are being revised. Other conterminous States are covered by an earlier series, as shown in figure 11.

Metropolitan-area maps

Metropolitan-area maps are prepared by combining on one or more sheets the 7½-minute quadrangles that cover a metropolitan area. Maps of 59 metropolitan areas have been published, including 3 revised maps that were completed during fiscal year 1966. Work in progress includes the revision of 6 others. Maps in the Metropolitan Area series include:

PUBLISHED

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.
Honolulu, Hawaii
Houston, Tex.
Indianapolis, Ind.
Juneau, Alaska
Knoxville, Tenn.
Little Rock, Ark.
Long Beach, Calif.
Los Angeles, Calif. (2 sheets)
Louisville, Ky.
Madison, Wis.
Milwaukee, Wis.
Minneapolis–St. Paul, Minn.
New Haven, Conn.
New Orleans, La.
New York, N.Y. (8 sheets)
Norfolk–Portsmouth–Newport News, Va.
Oakland, Calif.
Peoria, Ill.
Philadelphia, Pa. (2 sheets)
Pittsburgh, Pa.
Portland – Vancouver, Oreg.-Wash.
Rochester, N.Y.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
San Juan, P.R.
Seattle, Wash.
Shreveport, La.
Spokane, Wash.
Tacoma, Wash.
Toledo, Ohio
Washington, D.C.
Wichita, Kans.
Wilkes-Barre–Pittston, Pa.
Wilmington, Del.
Worcester, Mass.
Youngstown, Ohio

IN REVISION

Baton Rouge, La.
Chicago, Ill.
Salt Lake City, Utah
San Juan, P.R.
Spokane, Wash.
Washington, D.C.

National park maps

Maps of 40 of the 203 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 standard quadrangle series. Work in progress includes one new map and the revision of one map. Published maps in the National Park series include:

PUBLISHED

Acadia National Park, Maine
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
Colonial National Historical Park (Yorktown), Va.
Colorado National Monument, Colo.
Crater Lake National Park, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Colo.-Utah
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz. (2 sheets)
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, N.C.-Tenn. (2 sheets)
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Olympic National Park, Wash.
Petrified Forest National Monument, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and Kings Canyon National Parks, Calif.
Shenandoah National Park, Va. (2 sheets)
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.
Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyo.-Mont.-Idaho.
Yosemite National Park, Calif.
Yosemite Valley, Calif.
Zion National Park (Kolob Section), Utah
Zion National Park (Zion Canyon Section), Utah

IN PROGRESS

New Map

Badlands National Monument, S. Dak.

Revision

Sequoia and Kings Canyon National Parks, Calif.

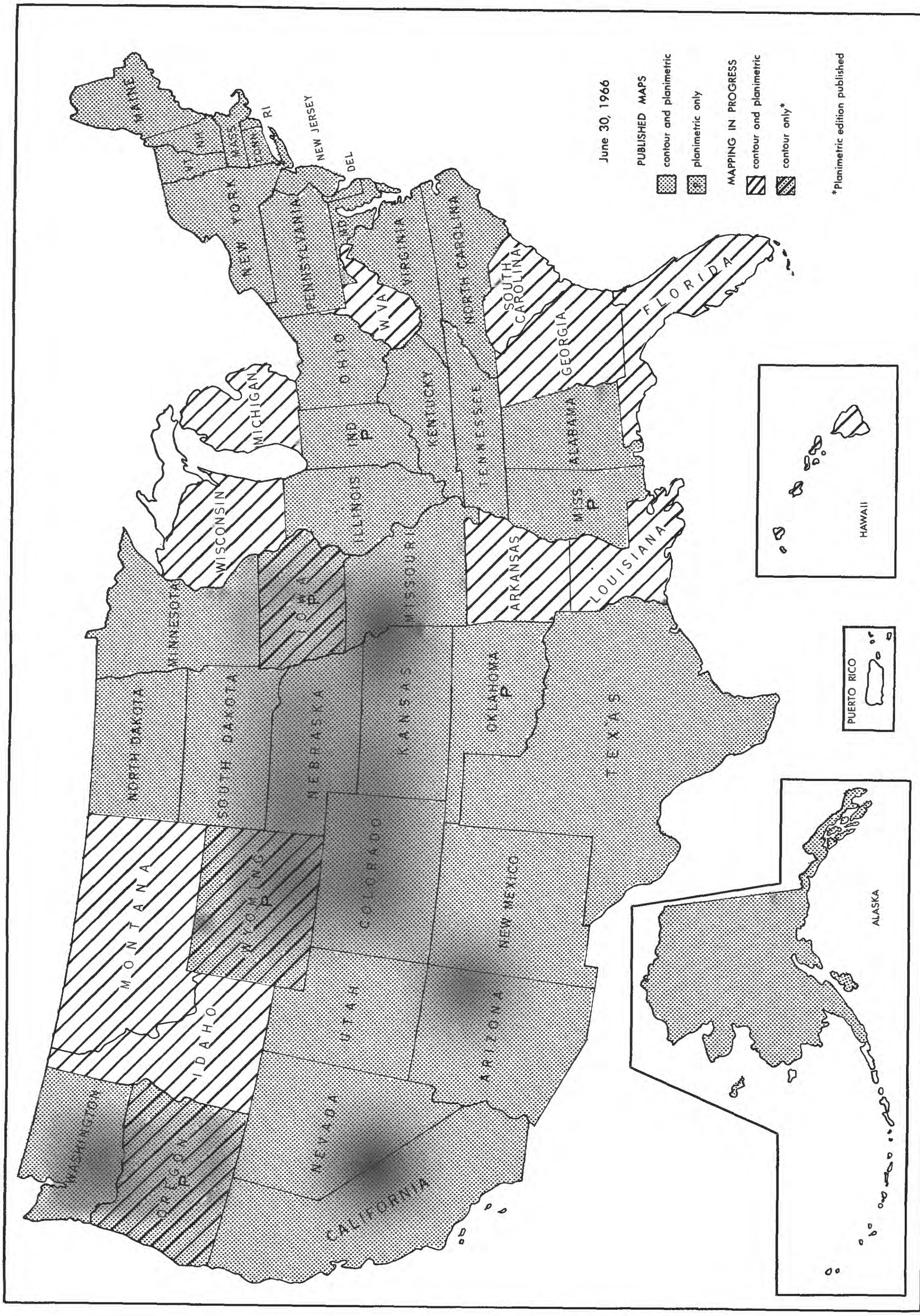

FIGURE 11.—Status of State topographic maps.

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). Seventeen 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 of 1:1,000,000 scale. Eventually this military series will be modified slightly and published in the IMW series (fig. 12).

Three of the maps, Hudson River, Mississippi Delta, and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey 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.

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: Lake Superior, Pikes Peak, Blue Ridge, Mount Whitney, and Quebec.

Aerial photography

In fiscal year 1966, the Topographic Division contracted for aerial photography covering approximately 175,500 square miles of area in the United States. This total includes 163,470 square miles of vertical photography, 1,700 square miles of convergent low-oblique photography, 10,110 square miles of super-wide-angle photography, and 220 square miles of color photography. The average price in 1966 was $3 per square mile.

MAPPING IN ANTARCTICA

The topographic mapping of Antarctica, conducted as part of the United States Antarctic Research Program of the National Science Foundation, was continued during fiscal year 1966. Five topographic engineers went to Antarctica during the austral summer of 1965–66 to obtain geodetic control for the topographic-mapping program and to execute surveys in support of geology, seismology, geophysics, and glaciology. Also, a specialist in aerial photography was assigned to Christchurch, New Zealand, for photographic liaison duty with the U.S. Navy.

Topographic field operations

E. R. Soza, J. R. Heiser, E. W. Rosser, and M. K. Weber completed 516 miles of electronic-distance traverse in the Pensacola Mountains, tying in previous surveys by T. E. Taylor in 1962–63 and by D. C. Barnett and J. R. Heiser in 1963–64. This year's traverse, which began in the Neptune Range and extended north through the Forrestal Range to Mount Spann and Mount Ferrara, also went south to the Aztec Range, completing ground-survey control for topographic mapping of the Pensacolas. At the midpoint and both ends of the traverse, lines were run 100 miles to either side to position seismic stations.

D. W. Ruthven assisted the regular party in an evaluation of the Geological Survey-developed AirBorne Control (ABC) system, as configured for the UH–1B helicopter. The system did not function properly, and later tests in the United States showed that the UH–1D helicopter is not capable of hovering in gusty winds with the accuracy required for surveying. Because the flight characteristics of the UH-1B and the UH–1D are nearly identical, lack of success of the ABC system in Antarctica is attributed to the hovering characteristics of the UH–1B helicopter.

Stakes were set out on the Ross Sea ice near McMurdo Station in November, and repositioned in February, in order to determine ice movement. The ice-strain net established in 1964–65 by E. R. Soza, Alfred Zavis, C. E. Morrison, and D. E. Reed at milepost 60 on Army-Navy Drive (U.S. Geol. Survey, r1929, p. A197) was remeasured.

A 1:25,000-scale topographic map of the Dufek Massif was prepared by E. W. Rosser at the request of the geological team. After laying out a base line with electronic distance-measuring instruments and altimeters, Rosser sketched the Massif using standard planetable procedure and terrestrial photographs.

Aerial photography

U.S. Navy Air Development Squadron 6 (VX-6) obtained aerial photographs for mapping in accordance with U.S. Geological Survey specifications. W. R. MacDonald was assigned to the U.S. Navy Photographic Laboratory at Christchurch, New Zealand, to advise on the quality of developed photographs and to assist with further planning and necessary reflights. MacDonald also served as visual navi-

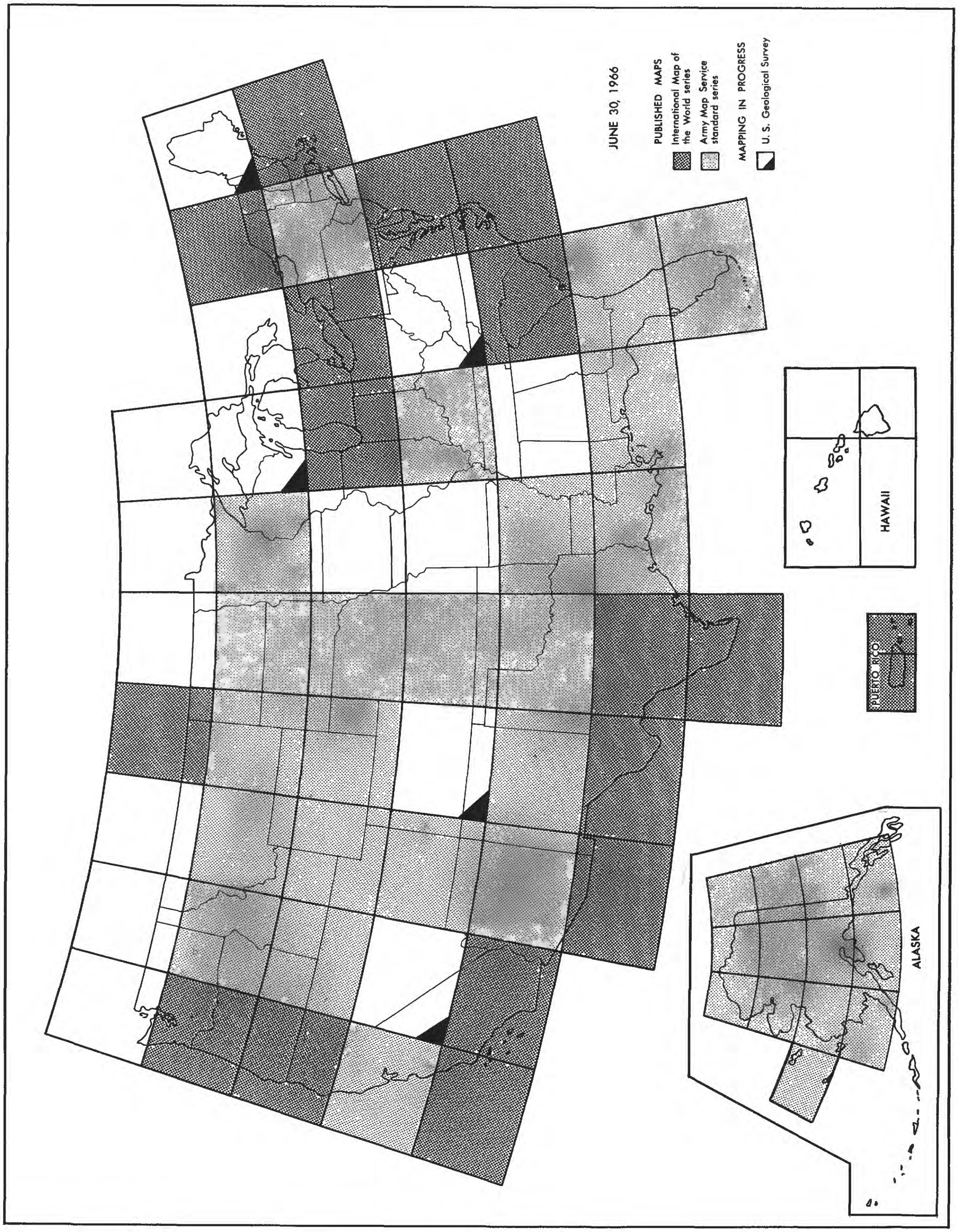

FIGURE 12.—Status of 1:1,000,000-scale topographic mapping.

gator on all photographic missions over the Antarctic continent.

About 140,000 square miles of mapping photography was obtained. For the first time, the cameras used in this program were equipped with Planigon lenses.

Cartographic activities

The status of U.S. Geological Survey topographic mapping is shown in figure 13. Twelve 1:250,000-scale topographic maps were published in shaded-relief editions in fiscal year 1966—6 of the Queen Alexandra Range and 6 of the Britannia Range. Mapping at the same scale is in progress for 10 sheets in the Queen Maud Range, 3 in the Queen Alexandra Range, 18 in Northern Victoria Land, and 2 in the Heritage Range. Work was also started on maps of the Pensacola Mountains. A planimetric manuscript covering about 60,000 square miles of western Marie Byrd Land was compiled, and will be published in a shaded-relief edition at 1:500,000 scale.

NATIONAL ATLAS

Approximately half of the maps for the National Atlas are in preparation, with progress the most advanced on the physical and historical sections. Experiments in using automatic plotters to locate positions and classes of information from automatic data-processing records of other agencies showed that use of these plotters will facilitate the compilation of most of the remaining thematic maps and should reduce the time and cost of map compilation. Paper, plastics, and cover fabrics were tested, and specifications for these items will be written early in 1967.

RESEARCH AND DEVELOPMENT

To support the National Topographic Program, continuing research and development are needed to improve techniques, instruments, and materials. The chief objectives of the program are to improve the quality and usability of the maps and to reduce the cost of producing them.

PHOTOMAPS OF OKEFENOKEE SWAMP

Many research projects in topographic surveying and mapping require a group effort by engineers and cartographers with different backgrounds and talents to achieve useful and meaningful results. One such project completed in 1966 was the preparation of an experimental photomap of the Chesser Island quadrangle, Georgia, a part of the Okefenokee Swamp.

Conventional line-drawn maps do not provide a satisfactory portrayal of large swamp areas because a uniform symbol pattern is used to represent the intricate detail shown by the aerial photographs from which the maps are compiled. Consequently, when requests were received for complete mapping of the Okefenokee Swamp, efforts were begun to develop better ways of portraying the features of the swamp. Experimentation was directed toward combining photoimagery and cartographic representation.

As the swamp is virtually flat, normal contouring was rejected in favor of spot elevations on the land, and water-surface elevations. The extreme difficulty of surveying in the swamp was overcome by using the AirBorne Control system to establish elevations, accurate within 1 foot, at more than 300 photoidentifiable locations within the swamp. A precise photomosaic of a representative quadrangle (Chesser Island) was prepared, and photoline and phototone negatives were made from the mosaic, for use in processing the photoimagery. The photoline negative is similar in appearance to a line drawing, with the edges of feature images enhanced and intermediate tones eliminated. The phototone negative retains the continuous-tone appearance but consists of random patterns of irregularly shaped dots. Both types of negative can be used to make lithographic pressplates without screening. Color-separation masks were prepared by extensive photointerpretation, so that the distinctive features of the swamp could be shown in near-natural colors. Finally, line symbols and lettering were added to show roads, canals, boundaries, boat trails, names, elevations, and the usual marginal information.

An experimental edition of the Chesser Island map, approved for publication after many trial printings, will serve as a guide in the production of the other 15 photomaps needed to provide complete coverage of the Okefenokee Swamp. About half of these maps will be published in 1967, and the rest in 1968.

AUTOMATION IN PROGRAM MANAGEMENT

To assure maximum efficiency in the use of funds, manpower, and equipment through effective managerial control, research in automation of programing and accounting and in the development of new management systems was continued and intensified during fiscal year 1966. A comprehensive magnetic-tape file on mapping data has been started. Intended as a library of historical, planning, statistical, financial, and operational information about each quadrangle map, the data bank is designed for automatic retrieval and analysis of the data. From the data bank, selected

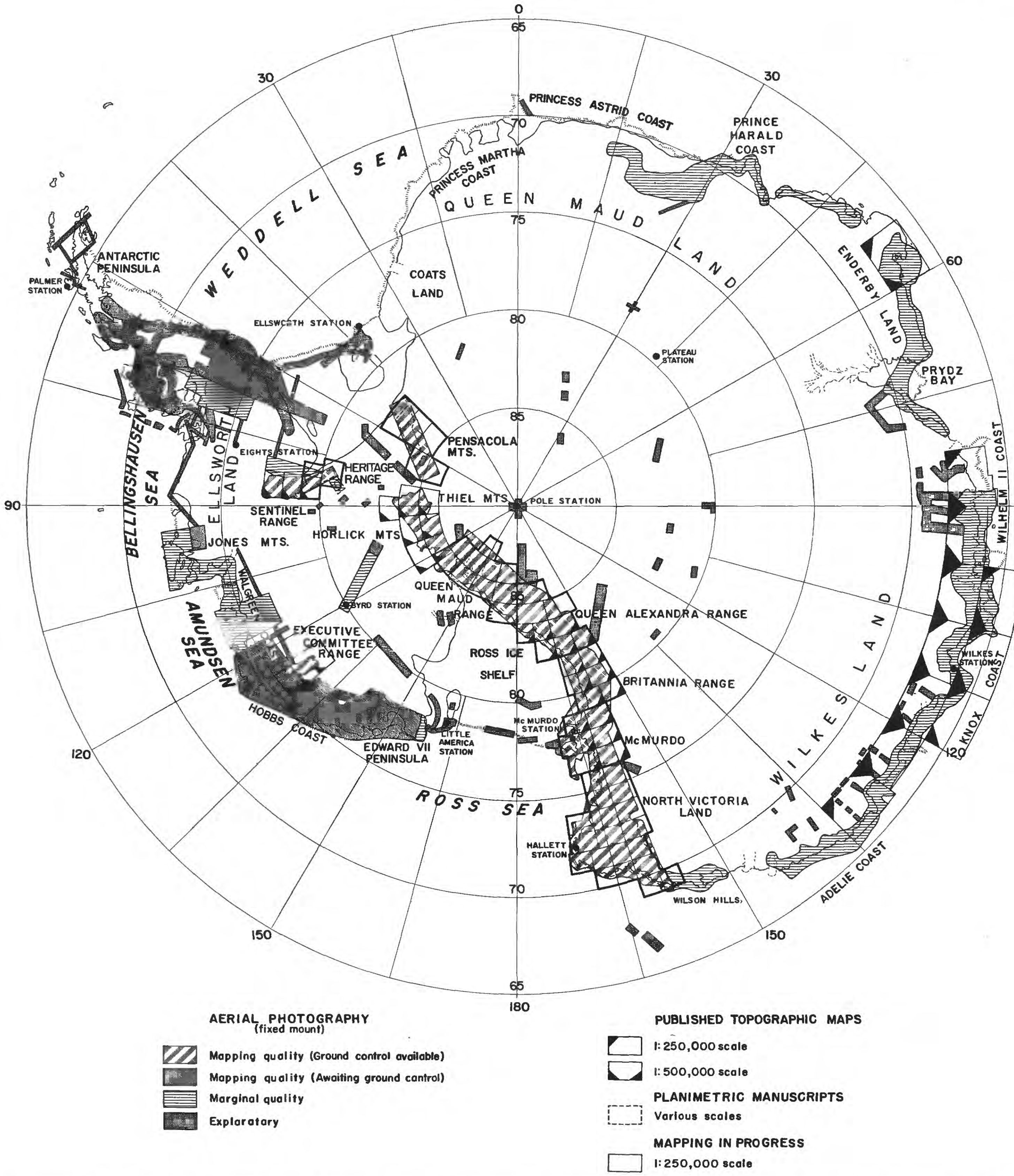

FIGURE 13.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1966.

information can be printed out as needed, as typed lists or, where appropriate, as a plot on a 1:4,500,000-scale sectional base map of the United States. The graphic type of printout has been used to facilitate the annual analysis of requests for mapping and the determination of mapping priorities.

A new accounting system has been designed and is being tested. In this system, reports of costs, production, schedules, and man-hours are prepared in a form suitable for computer processing. The system is correlated with the management-data bank, the mapping program, and the Bureau payroll system.

An automated program system is being designed to balance manpower and fiscal resources against mapping requirements for each of six successive fiscal years, providing the means for effective scheduling of mapping operations.

FIELD SURVEYS

Level-rod calibration

A transverse comparator already in use has been modified during the past year for precise calibration of level rods, and a computer program has been prepared to use the calibrator data for determining the accuracy of the rods and for computing corrections to be applied to rod readings. The accuracy of the calibration system is better than 1 part in 100,000.

The comparator consists of a movable carriage and of three reading microscopes equipped with special lighting systems to eliminate parallax in readings. The carriage holds the level rod to be calibrated and the reference standard, an invar meter/yard bar calibrated by the National Bureau of Standards in 1965 and found to be correct within 1 micron. Each half-yard interval of the level rod is measured 4 times, by 2 observers—twice with the left and center microscopes and twice with the right and center microscopes. These data are transferred to punched cards for input to the electronic computer. The computer calculates the errors in graduations, the line of best fit, deviations of errors from the line of best fit, and the overall accuracy. It also plots a graph of the line of best fit and the errors. The computation takes only a few seconds, whereas equivalent desk-calculator computation takes about 5 hours.

The new calibration system is intended to screen out rods with errors larger than 1 part in 30,000, to pair rods which have approximately equal accuracy, and to determine correction factors for use in adjusting lines of leveling that contain differences of elevation large enough for rod errors to be significant.

Stability tests of truck-mounted tower

A truck-mounted, hydraulic-lift surveying tower (p. B218–B221), equipped with a stabilization tank at the base of the inner unit, was set up on the grounds of the U.S. Bureau of Public Roads research station near Langley, Va., for tests of operating characteristics at heights of 42 and 72 feet. The tests comprised 100 sets of horizontal angle measurements at the 42-foot height and 50 sets at the 72-foot height, over an observing period of 4 months.

After the tower is erected, the stabilization tank is filled with 110 gallons of ethylene glycol by gravity flow from tanks on the truck. This fluid adds about 1,000 pounds to the weight of the inner tower, which supports the theodolite, and eliminates the need for guy wires when the tower is used at heights of 42 feet or less. For heights above 42 feet, the inner tower must be guyed. Wires are attached near the middle of the tower and anchored as close to the base of the tower as practicable to put the tower in compression.

Wind vibration is the most serious hindrance to accurate measurement of angles from the tower. The maximum allowable wind speed, at the 42-foot height, is about 20 miles an hour; at the 72-foot height the allowable maximum is about 15 miles an hour. Two kinds of motion due to wind were observed—a short-period vibration of 2 to 5 cycles per second, and a long-period sway lasting 30 seconds to 1 minute. The short-period vibration has little effect on the measurement of horizontal angles but seriously hampers the measurement of vertical angles. It can be damped by holding the tube of the instrument stand. The long-period sway causes serious errors in both horizontal and vertical angles.

Solar heating also causes two kinds of movement—a rotational motion about the vertical axis, which appears to follow the sun's path; and a lateral movement away from the sun, which is most noticeable when direct sunlight is intermittent, owing to scattered clouds. These motions can cause serious errors if large temperature differences occur.

In spite of all these difficulties, the accuracy of angles measured from the tower is comparable to that of angles measured on the ground, provided that proper precautions are taken in observational procedures.

Determining atmospheric refraction from meteorological data

Modern precise theodolites and electronic distance-measuring instruments reduce instrumental errors to virtual insignificance when suitable observing procedures are followed. Atmospheric refraction, however, remains a major source of error. A practical field method for determining the effective index of refraction over the sightline or microwave-beam path would therefore have wide application in field surveying.

Field tests have been carried out, during the past year, to develop a method of determining accurate values of atmospheric refraction from meteorological data. Most of the meteorological data were obtained through the cooperation of the U.S. Weather Bureau, which maintains a network of experimental stations in the Washington, D.C., metropolitan area. Temperature, wind speed, humidity, and other meteorological conditions are recorded continuously and automatically at these station. Some of the stations are instrumented towers at which data are measured at several heights.

After elevations and horizontal positions were established at selected towers, vertical angles were measured, in both directions, between the towers and survey stations 1 mile, 6 miles, and 12 miles away. The angles were measured repeatedly, at various hours of day and night and under a wide range of weather conditions. The value of atmospheric refraction for each observation was computed from the meteorological data for the time of observation and checked against the value determined from the observed vertical angles and known elevations.

Analysis of the data, still in progress, suggests that field measurement of the variation of temperature with height is not a practical technique because of the number and precision of the temperature readings required for meteorological computations. As an unexpected and possibly useful result, a correlation has been noted between net solar radiation and the magnitude of refraction. Since radiation is much easier to measure than precise air temperatures, this correlation will be investigated further.

PHOTOGRAMMETRY

Analytical aerotriangulation

The fully analytical direct geodetic constraint method (U.S. Geol. Survey, r1929, p. A201) has been used in a production trial to provide photogrammetric control for mapping the Middleburg and Arcola, Va., quadrangles. Input data for the computer program, in the form of x and y photograph coordinates measured with a monocomparator, were obtained from 50 glass-plate photographs taken at a flight height of 12,000 feet. For the adjustment, 4 horizontal and 25 vertical ground-control points were used as constraints. The root-mean-square horizontal and vertical errors were 4 feet and 1 foot, respectively.

A further and more extensive operational test of the method is underway, in which photogrammetric control for eleven 7½-minute quadrangles near Bowling Green, Va., will be established. Plastic targets were placed at all ground control points before the aerial photographs were taken in the spring of 1966, to provide positively identifiable and precisely measurable images on the photographs. Measurement of photocoordinates will begin early in fiscal year 1967.

A three-plate stereocomparator has been ordered to provide comparative data on the efficiency, convenience, and accuracy of different types of comparators. Photocoordinates for analytical aerotriangulation will continue to be measured on monocomparators until the new stereocomparator becomes available.

A standard coordinatograph is being modified for automatic operation by the addition of servomechanisms, electronic-control circuitry, and a paper-tape reader for input. It will be used for automatic plotting of horizontal-control positions determined by analytical and seminanalytical methods. Auxiliary command programs are available to provide completely automatic production of base sheets, including the plotting of graticule and grid lines and the printing of needed numeric and alphabetic data.

Semianalytical aerotriangulation

Semianalytical methods of aerotriangulation differ from the analytical methods in that the basic unit dealt with in the former is the photogrammetric model rather than the photograph, and in that the x and y (and sometimes z) coordinates are measured with conventional analog stereoplotting instruments equipped with encoders and analog-to-digital converters instead of comparators. The coordinates are then correlated, adjusted, and fitted to ground control by means of electronic computers.

Many semianalytical methods have been developed and are in various stages of productive use, and newer methods are continually being developed. These methods generally are designed to use available computers, and with stereoplotting equipment (such as Kelsh, ER–55, Wild, and Stereoplanigraph plotters), which can be equipped for digital readout by inexpensive attachments. A significant part of the aerotriangulation for standard mapping in the Topographic Division is now being done by semianalytical methods.

For general application, a new semianalytical method has been designed to use x and y coordinates obtained from independent, unbridged stereomodels. The computer program first connects the successive models into a block oriented to a common coordinate system by means of a linear conformal transformation. The block coordinates are then adjusted to the ground control by a linear transformation and a least-squares adjustment. The program can accommodate 24 blocks of 24 models each, a total of 576 stereomodels.

Another newly developed program provides an analytical adjustment of elevations based on x, y, and z coordinates obtained from strips of photographs bridged with a Wild A7 stereoplotter. The program has been successfully tested with data from 3 projects containing a total of ten 7½-minute quadrangles.

Test-site data

Last year the Topographic Division established a test site 16 miles square, with a high density of control points, within the U.S. Army Map Service Test Range near Phoenix, Ariz. Information on the control positions and elevations, station targets, and photographic coverage for the test site has been assembled in a data catalog and distributed within the Topographic Division and to several Federal mapping agencies. The test-site data have already been used for tests of super-wide-angle stereoplotters. In a study now underway, the relative merits of glass-plate photographs and film photographs for use in aerotriangulation are being determined through use of the test-site data.

Super-wide-angle photographs

The use of super-wide-angle photographs promises significant reduction in the costs of photogrammetric mapping, because photographs taken with super-wide-angle (120°) cameras cover 3 times the area of those taken at the same flight height with wide-angle (90°) cameras.

Following research tests of available super-wide-angle plotters, several quadrangle maps have been compiled with these plotters and subjected to thorough field tests for content and accuracy. The results indicate that maps compiled on the best super-wide-angle plotters will meet National Map Accuracy Standards. A study is underway to determine the feasibility of using high-altitude super-wide-angle photographs for compiling planimetry and for providing control for low-altitude photographs which would be used for contouring.

Color photographs for mapping

Photogrammetric applications of color aerial photographs have been expected and discussed for more than three decades, but problems of slow emulsion speeds, narrow exposure latitude, difficult processing, and lack of products specifically designed for photogrammetry have delayed practical results until recently. Several color emulsions and related products are now available for photogrammetric use and are being evaluated for their applicability in topographic mapping.

The Thebes NW, Ill., 7½-minute quadrangle has been stereocompiled from color aerial photographs and field tested for accuracy and completeness. The color images provided an advantage over black-and-white photographs in interpreting features and delineating planimetric detail. Some improvement also was noted in the contouring of flat areas and areas covered by dense coniferous timber.

Further research is underway to evaluate a new color-photography system in which Kodak Special Ektachrome MS Aerographic film is processed to color negatives. Color prints and diapositives or black-and-white prints and diapositives can be made from the color negatives, as desired. Parts of the Starrucca, Pa., mapping project will be mapped from aerial negatives and diapositives of the new type, as well as from normal black-and-white negatives and diapositives. The color and black-and-white photographs will be taken at the same time. Similar test projects are being planned for other areas which have various types of terrain characteristics.

Photogrammetric evaluation of map accuracy

The relative horizontal accuracy of a map has been proposed as a measure of the difficulty to be expected in adding new planimetric detail to the map during revision. As an economical means of evaluating relative horizontal accuracy, a photogrammetric method has been tested in which a statistical comparison is made between the map and an orthophotograph of the same area.

In preparation for a revision project, eight quadrangles of the Detroit, Mich., area were evaluated by the photogrammetric method. A coordinatograph equipped with automatic digital readout was used to measure the coordinates of selected map points and the coordinates of corresponding image points on orthophotographs prepared from high-altitude perspective photographs. The two sets of coordinates for each quadrangle were correlated and adjusted on an electronic computer to obtain a listing of position discrepancies for individual points and a root-mean-square discrepancy (RMSD) for the quadrangle. The discrepancies ranged from 20.9 feet to 37.6 feet for the 8 quadrangles. On the basis of this test, the existing map manuscripts were adjudged adequate for the addition of revised data. Further tests are needed to establish a limiting RMSD value which would indicate a map too poor to be used as a base in revision.

CARTOGRAPHY

Development of photoimage maps

The general interest in photoimage maps as an effective means of portraying terrain detail has been confirmed and intensified by the production of a map of the Chesser Island quadrangle, in the Okefenokee Swamp, Ga., described on page A202. Research is continuing in an effort to improve the production techniques and color rendition of photomaps and to determine types of areas for which photoimage representation is most effective. A photomap representation similar to that provided by the Chesser Island map is being prepared for a sample quadrangle of the Florida Everglades.

Other experimental photomaps will be prepared for other parts of the United States, at 1:24,000 scale for average areas and 1:12,000 for densely populated areas. Most of these areas have enough terrain relief to require the use of orthophotographs, which are processed from conventional perspective aerial photographs to remove errors due to differences of elevation.

Instrumentation and procedures

Instrumental developments during the year included the redesign of the register punch used to assure correct correlation of the separate color-separation plates. In the new punch, the sheets to be punched are held flat by a vacuum holddown plate, and the punches are operated by compressed air. The punch can accommodate a sheet size of 50 by 72 inches.

An improved tripod swivel graver has been developed, incorporating a large-aperture, ring-type ball bearing, with the inner race of the bearing supporting twin cutting points. The graver is easily controlled, and the open-center bearing permits a clear view of the scribing points and the lines being scribed.

As more and more of the country becomes covered with the standard quadrangle maps, attention is being turned toward techniques for revising and updating these series. Experimental printings have been prepared in which all changes in the map content are shown in a distinctive color. Showing all revised data in a separate color may be an economical means of updating maps that do not need extensive changes or do not warrant complete revision.

Geographic publications

Three compilations of data have been published or are being prepared for publication, as byproducts of map editing and geographic-names research: (1) Geological Survey Bulletin 1212, "Boundaries of the United States and the Several States"; this compendium of information on the National and State boundaries, first published in 1885, has been revised to include information available through 1964. (2) Geological Survey Bulletin 1245, "Delaware Place Names"; production of this bulletin was expedited by storing the entries on punched tape and using the tape to control an automatic typesetting machine. (3) Geological Survey Professional Paper 567, "Dictionary of Alaska Place Names." This publication, estimated at 1,200–1,400 pages, will list all known geographic names in Alaska, a bibliography of sources, data on authorities and explorers, a glossary of terms, and maps and photographs. Printed copies will be available for the Alaska Centennial in 1967.

SPACE TECHNOLOGY

The Topographic Division is cooperating with the National Aeronautics and Space Administration in cartographic research for support of the Apollo Manned Lunar and Earth-Orbital programs. This research is concerned with the design and development of high-resolution camera systems to be used on Apollo spacecraft, and with development of methods of compiling maps, charts, and other data from the photographs to be obtained in the Apollo missions.

As panoramic cameras offer the greatest potential for high resolution and definition, research has been directed toward determining the photographic and geometric characteristics of available panoramic cameras, in preparation for designing a camera and data-reduction system compatible with the spacecraft.

Other studies are directed toward perfecting techniques for preparing photomosaics and orthophotomosaics from rectified panoramic photographs.

PUBLICATIONS PROGRAM

Results of research and investigations by the 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 Government Printing Office. 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 of these lists of publications are free upon request to the GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242. They may be consulted at many public and educational-institution libraries, and at the Geological Survey offices named below.

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 second-hand books.

PUBLICATIONS ISSUED

During fiscal-year 1966, 281 technical book reports were published (357 in fiscal year 1965). Maps printed totaled 4,518, comprising some 19,868,000 copies, as follows:

Kind of map	FY 1965	FY 1966
Topographic	3, 323	3, 593
Geologic and hydrologic	285	314
Maps for inclusion in book reports	345	208
Miscellaneous and maps for other agencies	399	403
Total	4, 352	4, 518

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 at these and 12 other Survey offices, as well as by some 650 authorized commercial dealers throughout the United States who sell Survey maps locally.

In addition to approximately 58,500,000 maps and books on hand at the beginning of the year, 16,339,000 copies of new and reprinted maps and 500,000 copies of book reports were received. Distribution of 7,-482,000 copies of maps (including 560,000 index maps) was a 12-percent increase over the corresponding total for fiscal-year 1965. During fiscal-year 1966 the Geological Survey distributed 483,000 book reports for official use (down 23 percent from last year). In addition, 164,000 copies of the monthly announcement of new publications, 150,000 copies of the information booklet on topographic maps and 223,000 copies of other Survey leaflets, and 275,000 copies of the topographic-map symbol sheet were distributed.

The total distribution was implemented by 364,250 individual orders. Seventy-two percent of the nearly 7½ million maps distributed was sold, and $1,093,-823.76 was deposited to miscellaneous receipts in the U.S. Treasury ($956,290.28 in fiscal year 1965).

Map- and book-distribution activity during the last 2 years is summarized as follows:

Distribution point	FY 1965	FY 1966	Change (percent)
Arlington	4, 187, 350	4, 554, 850	+9
Denver	2, 526, 250	2, 768, 850	+10
Fairbanks	59, 450	75, 100	+26
Twelve other Survey offices	535, 750	566, 700	+6
Total	7, 308, 800	7, 965, 500	+9

HOW TO ORDER PUBLICATIONS

Ordering book reports

Professional papers, bulletins, water-supply papers, and miscellaneous book publications can be purchased from the SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 20402. Prepayment is required and may be made by money order or check payable to that office, or in cash—exact amount—at sender's risk. Postage stamps are not accepted. Book publications also may be purchased on an *over-the-counter* basis from the Geological Survey Public Inquiries Office listed on p. A217.

Circulars which are not out of print may be obtained free on application to the GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Ordering maps and charts

Maps, charts, folios, and hydrologic atlases are sold by the Geological Survey. *Mail* orders for those covering areas east of the Mississippi River should be addressed to the GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242, and for areas west of the Mississippi River to the GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLO. 80225. Remittances should be sent by check or money order made payable to the Geological Survey, or in cash—exact amount—at sender's risk. Postage stamps are not accepted. Retail prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. On an order amounting to $20 or more at the retail price, 20-percent discount is allowed; on orders of $100 or more, 40 percent is allowed. Most geologic maps are sent folded in envelopes unless flat copies are requested. Topographic maps are sent flat, except for orders of six maps or less; however, flat copies will also be sent for small orders on request. These publications also may be obtained on an area basis, by *over-the-counter* sale (but not by mail) from the Geological Survey Public Inquiries Office listed on p. A217. Residents of Alaska may order Alaska maps from the GEOLOGICAL SURVEY, 310 FIRST AVE., FAIRBANKS, ALASKA 99701.

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 of 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 of State index maps. 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 advance materials should be directed to the MAP INFORMATION OFFICE, GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Surface-water and quality-of-water records of [State]

Pending publication of surface-water records and quality-of-water records at 5-year intervals in the water-supply paper series on the basis of drainage basins, streamflow records and quality-of-water records are being released in separate annual reports (1) "Surface Water Records of [State]" and (2) "Water Quality Records in [State]" on the basis of State boundaries. Distribution of these basic-data reports, which are free on request, is limited and primarily for local needs. Those interested should write to the the State or States for which records are needed.

State water-resources investigations folders

A series of 8- by 10½-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, Guam, American Samoa, and Okinawa. As the programs change, the folders are revised. The folders are available free on request to the 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 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 A217 to A221, or interested State agencies. Many open-file reports are replaced later by formally printed publications.

COOPERATORS DURING FISCAL YEAR 1966

FEDERAL COOPERATORS

Agency for International Development
Atomic Energy Commission:
- Division of Isotopes Development
- Division of Military Applications
- Division of Raw Materials
- Division of Reactor Development and Technology
- Los Alamos Scientific Laboratory
- Nevada Operations Office
- Research Division
- San Francisco Operations Office
- Savannah River Operations Office

Department of Agriculture:
- Agricultural Research Service
- Forest Service
- Soil Conservation Service

Department of the Air Force:
- Arnold Engineering Development Center
- Cambridge Research Center
- Special Weapons Center
- Strategic Air Command
- Technical Applications Center
- Individual installations

Department of the Army:
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Corps of Engineers
- Individual Installations

Department of Commerce:
- Weather Bureau

Department of Defense:
- Advanced Research Projects Agency
- Defense Intelligence Agency
- Office of Scientific Research
- *See also* Department of the Air Force, Department of the Army, *and* Department of the Navy

Department of Health, Education and Welfare:
- Public Health Service

Department of the Interior:
- Boneville Power Administration
- Bureau of Commercial Fisheries
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- Federal Water Pollution Control Administration
- National Park Service
- Office of Minerals Exploration
- Office of Saline Water
- Office of Territories:
  - American Samoa
  - Guam
  - Virgin Islands

Department of the Interior—Continued
- The Alaska Railroad
- Trust Territory of the Pacific Islands

Department of Justice
Department of the Navy:
- Office of Naval Research
- Petroleum and Oil Shale Reserve
- Individual installations

Department of State
District of Columbia
Executive Office of the President—Office of Emergency Planning
Federal Aviation Agency
General Services Administration
National Science Foundation
Puerto Rico:
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Public Works
- Puerto Rico Water Resources Authority

Tennessee Valley Authority

STATE, COUNTY, AND MUNICIPAL COOPERATORS

Alabama:
- Alabama Department of Conservation
- Alabama Highway Department
- City of Mobile
- Geological Survey of Alabama
- Water Improvement Commission

Alaska:
- City of Anchorage
- City of Douglas
- City of Haines
- City of Port Chilkoot
- City of Skagway
- Greater Anchorage Area Borough
- Greater Juneau Borough
- State Department of Highways

Arizona:
- Apache County Superior Court
- Arizona Highway Department
- Arizona Interstate Stream Commission
- Buckeye Irrigation Company
- City of Flagstaff
- City of Tucson
- City of Williams
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District

Arizona—Continued
- Show Low Irrigation Company
- State Land Department
- University of Arizona

Arkansas:
- Arkansas Geological Commission
- Arkansas State Highway Commission
- University of Arkansas—Agricultural Experiment Station

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Calaveras County Water District
- California Department of Fish and Game
- California Department of Public Works—Division of Highways
- California Department of Water Resources
- California Water Quality Control Board
- City of San Diego
- City of Santa Barbara
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Lake Flood Control and Water Conservation District
- County of Los Angeles Department of County Engineers
- County of San Mateo
- Department of Conservation—Division of Mines and Geology
- East Bay Municipal Utility District
- East Kern County—Antelope Valley
- Georgetown Divide Public Utility
- Imperial Irrigation District
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Orange County Flood Control District
- Orange County Water District
- San Bernadino County Flood Control District
- San Bernadino Valley Water Conservation District
- San Francisco City and County Public Utilities Commission
- 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 Conservation District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Maria Valley Water Conservation District
- Soquel Creek County Water District
- Ventura River Municipal Water District

Colorado:
- Arkansas River Compact Administration
- City of Colorado Springs, Department of Public Utilities
- City and County of Denver, Board of Water Commissioners
- Colorado River Water Conservation District
- Colorado State Metal Mining Fund Board
- Colorado Water Conservation Board
- Costilla Creek Compact Commission

Colorado—Continued
- Department of Highways, State of Colorado
- Office of State Engineer
- Rio Grande Compact Commission
- Southeastern Colorado Water Conservation Board

Connecticut:
- City of Hartford—Department of Public Works
- City of New Britain—Board of Water Commissioners
- City of Torrington
- Connecticut Geologic and Natural History Survey
- Connecticut State Water Resources Commission
- Greater Hartford Flood Commissioners

District of Columbia:
- Department of Sanitary Engineering

Delaware:
- Delaware Geological Survey
- Delaware Highway Department

Florida:
- Board of Parks and Historic Memorials
- Broward County
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Jacksonville
- City of Miami
- City of Miami Beach
- City of Naples
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Collier County
- Dade County
- Florida Geological Survey
- Florida State Road Department
- Hillsborough County
- Orange County
- Polk County
- Trustees of the Internal Improvement Fund

Georgia:
- State Division of Conservation—Department of Mines, Mining and Geology
- State Highway Department

Hawaii:
- City and County of Honolulu
- Department of Land and Natural Resources

Idaho:
- Idaho Department of Highways
- Idaho Department of Reclamation

Illinois:
- Fountainhead Drainage District
- Northeastern Illinois Metropolitan Planning Commission
- Sanitary District of Bloom Township
- The Metropolitan Sanitary District of greater Chicago
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education—Water Survey Division

Indiana:
- Indiana Board of Health
- Indiana Department of Natural Resources—Bureau of Water and Mineral Resources
- Indiana Highway Commission

Iowa:
- City of Cedar Rapids
- City of Fort Dodge—Department of Municipal Utilities
- City of Iowa City
- Iowa Geological Survey
- Iowa State Conservation Commission
- Iowa State Highway Commission
- Iowa State University—Agricultural and Home Economics Experiment Station
- Linn County
- University of Iowa—Institute of Hydralic Research

Kansas:
- City of Wichita
- Kansas State Board of Agriculture
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas State Geological Survey
- State Highway Commission of Kansas

Kentucky:
- Kentucky Geological Survey
- University of Kentucky

Louisiana:
- Louisiana Department of Conservation—Louisiana Geological Survey
- Louisiana Department of Highways
- Louisiana Department of Public Works

Maine:
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- Baltimore County Department of Public Works
- City of Baltimore—Bureau of Water Supply, Department of Public Works
- City of Salisbury—Department of Public Works
- Maryland Department of Health—Division of Sanitary Engineering
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Maryland Planning Department
- Maryland State Road Commission
- University of Maryland—Department of Agricultural Engineering
- Washington Suburban Sanitary Commission

Massachusetts:
- Department of Natural Resources
- Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Metropolitan District Commission:
  - Construction Division
  - Water Division
- State Water Resources Commission

Michigan:
- Michigan Department of Conservation, Geological Survey Division
- State Water Resources Commission

Minnesota:
- Minnesota Department of Administration
- Minnesota Department of Conservation—Division of Waters
- Minnesota Department of Highways
- State Department of Iron Range Resources and Rehabilitation

Mississippi:
- City of Jackson
- Harrison County Board of Supervisors
- Harrison County Development Commission
- Jackson County Port Authority
- Mississippi Board of Water Commissioners
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pearl River Valley Water Supply District

Missouri:
- Conservation Commission:
  - Engineering Division
  - Fisheries Division
- Division of Geological Survey and Water Resources
- Department of Public Health and Welfare of Missouri—Water Pollution Board
- Highway Commission
- University of Missouri

Montana:
- Endowment and Research Foundation—Montana State College
- Montana Bureau of Mines and Geology
- Montana State Fish and Game Commission
- Montana State Highway Commission
- Montana State Water Conservation Board

Nebraska:
- Nebraska Department of Roads
- Nebraska Department of Water Resources
- University of Nebraska—Conservation and Survey Division

Nevada:
- Nevada Bureau of Mines
- Nevada Department of Conservation and Natural Resources—Division of Water Resources
- Nevada State Highway Department

New Hampshire:
- Department of Resources and Economic Development
- New Hampshire Water Resources Board

New Jersey:
- Camden County Planning Board
- County of Bergen
- Delaware River Basin Commission
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- State Department of Agriculture—State Soil Conservation Committee
- State Department of Conservation and Economic Development:
  - Division of Fish and Game
  - Division of Water Policy and Supply
- State Department of Health—Division of Environmental Health

New Mexico:
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Institute of Mining and Technology
- New Mexico State Engineer and School of Mines
- New Mexico State Engineer
- Pecos River Commission
- Rio Grande Compact Commission
- State Department of Game and Fish
- State Highway Department

New York:
- Board of Hudson River—Black River Regulating District
- Brighton Sewer Commission No. 2
- City of Albany—Department of Water and Water Supply
- City of Auburn—Water Department
- County of Dutchess—Board of Supervisors
- County of Nassau—Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Suffolk:
  - Department of Public Works
  - Water Authority
- County of Westchester
- Department of Conservation:
  - Division of Lands and Forests
  - Division of Water Resources
  - Water Resources Commission
- New York City Department of Water Supply, Gas and Electricity
- Oswegatchie River—Cranberry Reservoir Commission
- State Office of Atomic and Space Development
- State Department of Commerce
- State Department of Health—Water Pollution Control Board
- State Department of Public Works—Division of Construction, Waterways Operation and Maintenance Subdivision
- Village of Nyack—Board of Water Commissioners

North Carolina:
- City of Asheville—Public Works Department
- City of Belhaven
- City of Burlington
- City of Charlotte
- City of Durham—Department of Water Resources
- City of Greensboro
- City of Winston-Salem
- North Carolina Department of Conservation and Development—Division of Mineral Resources
- North Carolina State University—Physical Plant Division
- Pitt County Board of Commissioners
- State Department of Water Resources
- State Highway Commission
- Town of Waynesville
- Wake County Board of County Commissioners

North Dakota:
- North Dakota Geological Survey
- Oliver County—Board of County Commissioners
- State Highway Department
- State Water Conservation 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 Water
- Ohio River Valley Water Sanitation Commission

Oklahoma:
- City of Oklahoma City—Oklahoma City Water Department
- Oklahoma Department of Highways

Oklahoma—Continued
- Oklahoma Geological Survey
- Oklahoma Water Resources Board
- State Department of Health—Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Astoria
- City of Dalles City
- City of Eugene—Water and Electric Board
- City of McMinnville—Water and Light Department
- City of Monmouth
- City of Portland—Bureau of Water Works
- City of Toledo
- Coos Bay—North Bend Water Board
- Coos County—Board of Commissioners
- Douglas County Court
- Lane County—Board of County Commissioners
- Mosier Irrigation District
- Office of the State Engineer
- Oregon Board of Higher Education
- Oregon State Game Commission
- Oregon State University—Department of Fisheries and Wildlife
- State Highway Commission
- Talent Irrigation District

Pennsylvania:
- Chester County—Soil and Water Conservation District
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia Water Department
- Delaware River Master
- Pennsylvania Department of Agriculture—State Soil and Water Conservation Commission
- Pennsylvania Department of Forests and Waters
- Pennsylvania Department of Internal Affairs—Topographic and Geologic Survey

Rhode Island:
- State Department of Natural Resources—Division of Harbors and Rivers
- 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
- State Highway Department
- State Development Board
- State Public Service Authority
- State Water Pollution Control Authority

South Dakota:
- Highway Commission
- South Dakota State Geological Survey
- South Dakota State Water Resources Commission

Tennessee:
- City of Chattanooga
- City of Memphis—Light, Gas and Water Division
- City of Murfreesboro

Tennessee—Continued
- City of Oak Ridge
- Metropolitan Government of Nashville and Davidson County
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Highways
- Tennessee Department of Public Health—Division of Stream Pollution Control
- Tennessee Game and Fish Commission

Texas:
- City of Dallas—Public Works
- City of Houston—Public Works
- Pecos River Commission
- Rio Grande Compact Commission
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- Utah Geological and Mineralogical Survey
- Utah State Department of Highways
- Utah State Engineer
- Utah Water and Power Board

Vermont:
- State Department of Highways
- State Department of Water Resources

Virginia:
- City of Alexandria
- City of Charlottesville
- City of Newport News
- City of Norfolk
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Virginia Department of Highways

Washington:
- City of Seattle
- City of Tacoma:
  - Public Works
  - Public Utilities
- King County
- Municipality of Metropolitan Seattle
- Washington State Department of Conservation
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Pollution Control Commission

West Virginia:
- Clarksburg Water Board'
- Morgantown Water Commission
- West Virginia Department of Natural Resources—Division of Water Resources
- West Virginia Geological and Economic Survey
- West Virginia State Road Commission

Wisconsin:
- Madison Metropolitan Sewerage District
- Public Service Commission of Wisconsin
- Southeast Wisconsin Regional Planning Commission
- State Committe on Water Pollution
- State Highway Commission
- University of Wisconsin:
  - Department of Civil Engineering
  - Geological and Natural History Survey

Wyoming:
- City of Cheyenne
- State Highway Commission of Wyoming
- Wyoming Geological Survey
- Wyoming Natural Resource Board
- Wyoming State Agriculture Commission
- Wyoming State Engineer

OTHER COOPERATORS

Kingdom of Saudi Arabia
Permittees and licensees of the Federal Power Commission
United Nations in Thailand

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets NW., Washington, D.C. 20242; 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; BElmont 3-3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; DAvenport 5-6761

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage, 99501	Margaret I. Erwin (277-0577)	108 Skyline Bldg., 508 2d Ave.
California, Los Angeles, 90012	Lucy E. Birdsall (688-2850)	7638 Federal Bldg., 300 N. Los Angeles St.
San Francisco, 94111	Jean V. Molleskog (556-5627)	504 Custom House, 555 Battery St.
Colorado, Denver, 80202	Lorene C. Young (297-4169)	15426 Federal Bldg., 1961 Stout St.
Texas, Dallas, 75202	Mary E. Reid (RIverside 9-3230, ext. 3230).	602 Thomas Bldg., 1314 Wood St.
Utah, Salt Lake City, 84111	Maurine Clifford (524-5652)	8102 Federal Bldg., 125 South State St.
Washington, Spokane, 99204	Eva M. Raymond (TEmple 8-3361, ext. 121).	South 157 Howard St.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of September 1, 1966. Corresspondence to the following offices should be addressed to the Post Office Box, if one is given]

CONSERVATION DIVISION

Location	*Official in charge* and telephone number*	*Address*
Alaska, Anchorage, 99501	Leo H. Saarela (m) (277-0578), Alexander A. Wanek (c) (277-0570), W. J. Linton (o) (277-0579).	P.O. Box 259; Skyline Bldg., 218 E. St.
California, Los Angeles, 90012	Merrit B. Smith (c) (688-2846), D. W. Solanas (o) (688-2846).	7744 Federal Bldg., 300 N. Los Angeles St.
Sacramento, 95814	Kenneth W. Sax (w) (499-2203)	8030 Federal Bldg., 650 Capitol Ave.
Bakersfield, 93301	Harry Lee Wolf (o) and E. E. Richardson (c) (327-7201).	309 Federal Bldg., 800 Truxtun Ave.
Colorado, Denver, 80202	Edward R. Haymaker (o) (297-3211), John P. Storrs (m) (297-4038).	15428 and 15444 Federal Bldg.
Denver, 80225	George H. Horn (c) (233-8168)	Building 25, Federal Center.
Denver, 80202	William C. Senkpiel (w) (297-3316)	15407 Federal Bldg., 1961 Stout St.
Durango, 81302	Jerry W. Long (o) (247-5144)	P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.
Louisiana, New Orleans, 70113	Robert F. Evans (o) (527-6543)	T-6009 Federal Bldg., 701 Loyola Ave.
Lafayette, 70504	Jake B. Lowenhaupt (o) (232-0239)	301 Federal Bldg.
Montana, Billings, 59103	A. F. Czarnowsky (m) and Hillary A. Oden (o) (245-6711, ext. 6368).	P.O. Box 2550; 216 Federal Bldg.
Great Falls, 59401	Andrew F. Bateman (c) (454-3314), John A. Fraher (o) (454-3336).	P.O. Boxes 1215 and 2265; 510 First Ave.
New Mexico, Artesia, 88210	James A. Knauf (o) (746-4841)	Drawer U; 210 Carper Bldg., 105 S. 4th St.
Carlsbad, 88220	Robert S. Fulton (m) and Bruno R. Alto (c) (885-6454).	P.O. Box 1716; Federal Bldg., Fox and Haleguena Sts.
Farmington, 87401	Phillip T. McGrath (o) and J. E. Fassett (c) (325-4572).	P.O. Box 959; 409 Petroleum Club Plaza, 3535 East 30th St.

*The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: b—Branch of Connally Act Compliance, c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification.

Location	*Official in charge* and telephone number*	*Address*
New Mexico—Continued		
Hobbs, 88240	Arthur R. Brown (o) (393–3612)	Box 1157; 205 N. Linam St.
Roswell, 88201	J. A. Anderson (o) (622–9857), T. F. Stipp (c) (622–1332).	Drawer 1857; Farnsworth Bldg., 120 W. 2d St.
Oklahoma, Holdenville, 74748	Gerhardt H. W. Schuster (o) (379–3840)	P.O. Box 789; 5 Federal Bldg.
McAlester, 74502	A. M. Dinsmore (m) (423–5030)	509 South 3d St.
Miami, 74354	Donal F. Ziehl (m) (542–9481)	P.O. Box 509; 205 Federal Bldg.
Oklahoma City, 73102	Charley W. Nease (o) (236–2311)	4321 Federal Court House and Office Bldg., 220 N.W. 4th St.
Tulsa, 74103	Edward L. Johnson (c) and N. Orvis Frederick (o) (584–7161).	521 Wright Bldg., 115 W. 3d St.
Oregon, Portland, 97208	Loyd L. Young (w) (234–3996)	P.O. Box 3202; 830 N.E. Holladay St.
Utah, Salt Lake City, 84111	Ernest Blessing (m) (524–5646), Harry McAndrews (c) (524–5643), Rodney A. Smith (o) (524–5650).	8402, 8422, and 8416 Federal Bldg.; 125 S. State St.
Washington, Tacoma, 98401	Gordon C. Giles (w) (383–5380)	P.O. Box 1152; 244 Federal Bldg.
Wyoming, Casper, 82602	J. R. Schwabrow (o) (265–4310), Donald M. Van Sickle (c) (265–3270).	P.O. Box 400; 305 Federal Bldg.
Newcastle, 82701	Glenn E. Worden (o) (746–4554)	P.O. Box 219; 611 S. Summit St.
Rock Springs, 82901	John Duletsky (o) (362–6422), Arne A. Mattila (m) (362–7350).	P.O. Box 1170; 201 and 204 First Security Bank Bldg., 502 S. Front St.
Thermopolis, 82443	Charles P. Clifford (o) (864–3477)	P.O. Box 590; 202 Federal Bldg.

* See footnote, p. A217.

GEOLOGIC DIVISION

Location	*Official in charge and telephone number*	*Address*
Alaska, College, 99735	Robert M. Chapman (479–6725)	P.O. Box 580; Brooks Memorial Bldg.
Arizona, Flagstaff, 86002	Eugene M. Shoemaker (774–5081)	601 East Cedar Ave.
Hawaii, Hawaii National Park, 96718	Howard A. Powers (678–485)	Hawaiian Volcano Observatory.
Kansas, Lawrence, 66044	Windsor L. Adkison (VIking 3–2700)	c/o State Geological Survey, Lindley Hall, Univ. of Kansas.
Kentucky, Lexington, 40503	Paul W. Richards (4–2473)	496 Southland Drive.
Maryland, Beltsville, 20705	Dwight L. Schmidt (GRanite 4–4800, ext. 470).	U.S. Geological Survey Bldg., Dept. of Agriculture Research Center.
Massachusetts, Boston, 02116	Lincoln R. Page (KEnmore 6–1444)	Room 1, 270 Dartmouth St.
Michigan, Marquette, 49855	Jacob E. Gair (226–2110)	Industrial Lane.
New Mexico, Albuquerque, 87100	Charles B. Read (CHapel 7–0311, ext. 483)	P.O. Box 4083, Station A; Geology Bldg., Univ. of New Mexico.
Ohio, Columbus, 43200	James M. Schopf (AXminister 4–1810)	Orton Hall, Ohio State Univ., 155 S. Oval Drive.
Puerto Rico, Roosevelt, 00927	Reginald P. Briggs (San Juan 6–5340)	P.O. Box 803.
Tennessee, Knoxville, 37906	Robert A. Laurence (2–7787)	13 Post Office Bldg.
Texas, Austin, 78701	D. Hoye Eargle (HObart 5–6501)	801 Federal Bldg.
Utah, Salt Lake City, 84111	Lowell S. Hilpert (524–5640)	8426 Federal Bldg.
Washington, Spokane, 99204	Albert E. Weissenborn (TEmple 8–2084)	South 157 Howard St.
Wisconsin, Madison, 53706	Carl E. Dutton (262–1854)	222 Science Hall, Univ. of Wisconsin.
Wyoming, Laramie, 82070	J. David Love (FRanklin 5-4495)	Geology Hall, Univ. of Wyoming.

TOPOGRAPHIC DIVISION

Location	*Engineer in charge and telephone number*	*Address*
California, Menlo Park, 94025	Robert O. Davis (415 325–6761, ext. 411)	345 Middlefield Rd.
Colorado, Denver, 80225	Roland H. Moore (303 233–3611, ext. 8551).	Bldg. 25, Federal Center.
Missouri, Rolla, 65401	Daniel Kennedy (314 364–3680)	P.O. Box 133; 9th and Elm Sts.
Virginia, Arlington, 22201	Morris M. Thompson (703 JAckson 5–7550).	1109 N. Highland St.

WATER RESOURCES DIVISION

AREA OFFICES

Location	Official in charge* and telephone number	Address
Atlantic Coast Area: Arlington, Virginia 22209	George E. Ferguson, Area Hydrologist (202 343–4840).	George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Mid-Continent Area: St. Louis, Missouri 63103	Harry D. Wilson, Jr., Area Hydrologist (314 622–4361).	1252 Federal Bldg., 1520 Market St.
Rocky Mountain Area: Denver, Colorado 80225	Sherman K. Jackson, Area Hydrologist (303 233–6701).	Bldg. 25, Federal Center.
Pacific Coast Area: Menlo Park, California 94025	Warren W. Hastings, Area Hydrologist (415 325–6761, ext. 337, 338, 339).	345 Middlefield Road.

DISTRICT OFFICES

Location	Official in charge* and telephone number	Address
Alabama, University, 35486	William L. Broadhurst (w) (205 752–8105).	P.O. Box V; Oil and Gas Board Bldg., Univ. of Alabama, Tuscaloosa.
Alaska, Anchorage, 99501	Harry Hulsing (w) (907 277–5526, 5527)	P.O. Box 2480; 316 Skyline Bldg., Second and E Sts.
Arizona, Tucson, 85717	Horace M. Babcock (w) (602 623–7731, ext. 5791, 5792, 5793).	P.O. Box 4070; Geology Bldg., Univ. of Arizona Campus.
Arkansas, Little Rock, 72201	Richard T. Sniegocki (w) (501 372–5246, ext. 5270).	2301 Federal Office Bldg., 700 West Capitol Ave.
California, Menlo Park, 94025	Walter Hofmann (w) (415 325–6761, ext. 326, 327, 465, 466).	345 Middlefield Road.
Colorado, Denver, 80225	John W. Odell (s) (303 233–3611, ext. 6444), Leonard A. Wood (g) (303 233–3611, ext. 8546).	Bldg. 25, Federal Center.
Connecticut, Hartford, 06101	John Horton (s) (203 244–2528)	P.O. Box 715; 235 Federal Bldg.
Middletown, 06458	John A. Baker (g) (203 346–5542)	204 Post Office Bldg.
Delaware	*See* Maryland District Office	*See* Maryland District Office.
District of Columbia	*See* Maryland District Office	*See* Maryland District Office.
Florida, Tallahassee, 32304	Clyde S. Conover (w) (904 224–1203)	P.O. Box 2315; Gunter Bldg., Tennessee and Woodward Sts.
Georgia, Atlanta, 30323	Albert N. Cameron (w) (404 526–5663, 5664)	164 Peachtree Seventh Bldg.
Hawaii, Honolulu, 96814	Mearle M. Miller (w) (588–692, 693)	330 First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise, 83702	Wayne I. Travis (s) (208 342–2711, ext. 531), Herbert A. Waite (g) (208 342–2711, ext. 539).	Rm. 215 and 205, 914 Jefferson St.
Illinois, Champaign, 61820	William D. Mitchell (w) (217 356–5221)	605 South Neil St.
Indiana, Indianapolis, 46204	Malcolm D. Hale (w) (317 633–7398)	Rm. 516, 611 N. Park Ave.
Iowa, Iowa City, 52241	Sulo W. Wiitala (s) (319 338–0581, ext. 475).	508 Hydraulic Laboratory.
Iowa City, 52240	Walter L. Steinhilber (g) (319 338–1173)	Geological Survey Bldg.
Kansas, Lawrence, 66045	Robert J. Dingman (g) (913 864–3001)	c/o Univ. of Kansas.
Topeka, 66601	Edward J. Kennedy (s) (913 234–8661, ext. 201, 202).	P.O. Box 856; 403 Federal Bldg.
Kentucky, Louisville, 40202	Robert V. Cushman (g) and Floyd F. Schrader (s) (502 582–5241, 5242, 5243).	310 Center Bldg. 522 West Jefferson St.
Louisiana, Baton Rouge, 70806	Rex R. Meyer (w) (504 348–4281)	215 Prudential Bldg., 6554 Florida Blvd.
Maine, Augusta, 04330	Gordon S. Hayes (w) (207 623–4511, ext. 708).	Vickery Hill Bldg., Court St.
Maryland, Towson, 21204	John W. Wark (w) (301 828–7460)	724 York Road.
Massachusetts, Boston, 02110	Charles E. Knox (w) (617 223–2824)	Rm. 205, 211 Congress St.
Michigan, Lansing, 48933	Arlington D. Ash (w) (517 372–1910, ext. 561).	700 Capitol Savings and Loan Bldg.

* The small letter in parentheses following each official's name signifies his affiliation in the Water Resources Division, as follows: g—Ground Water Branch; q—Quality of Water Branch; s—Surface Water Branch; w—Water Resources Division.

DISTRICT OFFICES—Continued

Location	*Official in charge* and telephone number*	*Address*
Minnesota, St. Paul, 55101	David B. Anderson (s) and Richmond F. Brown (g) (612 222–8011, ext. 265).	1610 and 1002 New Post Office Bldg.
Mississippi, Jackson, 39205	William H. Robinson (w) (601 948–7821, ext. 326).	P.O. Box 2052; 302 U.S. Post Office Bldg.
Missouri, Rolla, 65401	Anthony Homyk, Jr. (s) (314 364–1599), Edward J. Harvey (g) (314 364–1599).	P.O. Box 340; 103 W. 10th St.
Montana, Billings, 59601	Charles W. Lane (w) (406 245–6711, ext. 6281).	P.O. Box 1818; 3424 Federal Bldg., 316 N. 26th St.
Nebraska, Lincoln, 68508	Kenneth A. MacKichan (w) (402 475–3643).	127 Nebraska Hall, 901 N. 17th St.
Nevada, Carson City, 89701	George F. Worts, Jr. (w) (702 882–1388).	222 E. Washington St.
New Hampshire	*See* Massachusetts District Office	*See* Massachusetts District Office.
New Jersey, Trenton, 08605	John E. McCall (s) (609 599–3511, ext. 214).	P.O. Box 967; 433 Federal Bldg.
Trenton, 08607	Allen Sinnott (g) (609 599–3511, ext. 213)	P.O. Box 1238; 432 Federal Bldg.
New Mexico, Albuquerque, 87106	William E. Hale (w) (505 247–0311, ext. 2246).	P.O. Box 4217; Geology Bldg., Univ. of New Mexico.
New York, Albany, 12201	Ralph C. Heath (w) (518 472–2457)	P.O. Box 948; 342 Federal Bldg.
North Carolina, Raleigh, 27602	Edward B. Rice (w) (919 828–9031, ext. 156, 157).	P.O. Box 2857; 4th Floor, Federal Bldg.
North Dakota, Bismarck, 58502	Harlan M. Erskine (s) (701 255–4011, ext. 227), Delbert W. Brown (g) (701 255–4011, ext. 228).	P.O. Box 778; 348 New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus, 43212	John J. Molloy (w) (614 469–5553, 5554)	554 U.S. Post Office Bldg. 85 Marconi Blvd.
Oklahoma, Oklahoma City, 73102	James H. Irwin (g) (405 236–2311, ext. 412), Alexander A. Fischback, Jr. (s) (405 236–2311, ext. 257, 258).	4011 and 4301 Federal Bldg, and U.S. Court House, 200 Northwest 4th St.
Oklahoma City, 73109	Richard P. Orth (q) (405 677–5022)	P.O. Box 95205; 2800 S. Eastern St.
Oregon, Portland, 97208	Roy B. Sanderson (s) (503 234–3361, ext. 1995), Eugene R. Hampton (g) (503 234–3361, ext. 1981), Lawrence Bodhaine (q) (503 234–3361, ext. 1994).	P.O. Boxes 3202, 3087, 3203; 830 NE. Holladay St.
Pennsylvania, Harrisburg, 17102	Joseph E. Barclay (g) (717 787–3420, 3421).	100 North Cameron St.
Harrisburg, 17104	Robert E. Steach (s) (717 787–3917)	1224 Mulberry St.
Philadelphia, 19106	Norman H. Beamer (q) (215 597–4420)	1302 U.S. Custom House, 2d and Chestnut Sts.
Puerto Rico, Hato Rey, 00918	Dean B. Bogart (w) (809 766–3310, 3311, 3315).	12 Arroyo St.
Rhode Island	*See* Massachusetts District Office	*See* Massachusetts District Office.
South Carolina, Columbia, 29204	Rolland W. Carter (w) (803 253–8371, ext. 401).	2346 Two Notch Road.
South Dakota, Huron, 57350	John E. Powell (g) (605 352–8651, ext. 293)	P.O. Box 1412; 231 Federal Bldg.
Pierre, 57501	John E. Wagar (s) (605 224–7856)	P.O. Box 220; 346 Federal Bldg.
Tennessee, Nashville, 37203	Joseph S. Cragwall, Jr. (w) (615 242–8321 ext. 5424).	144 Federal Bldg.
Texas, Austin, 78701	Trigg Twichell (w) (512 476–6551, 6561, 6571).	Federal Bldg., 300 E. 8th Ave.
Utah, Salt Lake City, 84111	Theodore Arnow (w) (801 524–5654, 5655)	8209 Federal Bldg., 125 S. State St.
Virginia, Charlottesville, 22903	James W. Gambrell (s) (703 296–5171, ext. 321).	P.O. Box 3327, University Station; Natural Resources Bldg.; McCormick Road.
Vermont	*See* Massachusetts District Office	*See* Massachusetts District Office.
Washington, Tacoma, 98402	Leslie B. Laird (w) (206 383–2861, ext. 384).	Rm. 300, 1305 Tacoma Avenue S.

See footnote, p. A219.

DISTRICT OFFICES—Continued

Location	Official in charge* and telephone number	Address
West Virginia, Charleston, 25301	William C. Griffin (w) (304 343-6181, ext. 310, 311).	3303 New Federal Bldg. and U.S. Court House; 500 Quarrier St. East.
Wisconsin, Madison, 53706	Charles L. R. Holt, Jr. (g) (608 262-2488)	175 Science Hall, Univ. of Wisconsin.
Madison, 53705	Kenneth B. Young (s) (608 233-0195)	5001 University Ave.
Wyoming, Cheyenne, 82002	Ellis D. Gordon (g) (307 634-5920, ext. 2331), Leon A. Wiard (s) (307 634-5920, ext. 2317).	P.O. Box 2087; 219 E. 8th Ave.
Worland, 82401	Thomas F. Hanley (q) (307 347-2181)	1214 Big Horn Ave.

*See footnote, p. A219.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	Official in charge	Address
Bolivia, La Paz	Reed J. Anderson	U.S. Geological Survey, U.S. AID/Bolivia, c/o American Embassy, La Paz, Bolivia.
Brazil, Rio de Janeiro	Max G. White	U.S. Geological Survey, U.S. AID/RIO, c/o American Embassy, APO New York 09676.
Colombia, Barranquilla	Charles M. Tschanz	U.S. Geological Survey, c/o American Consul, American Consulate, Barranquilla, Colombia.
Bogotá	Earl M. Irving	U.S. Geological Survey, U.S. AID/UID, c/o American Embassy, Bogotá, Colombia.
Bucaramanga	Dwight E. Ward	U.S. Geological Survey, U.S. AID/UID/Bogota, U.S. Dept. of State, Washington, D.C. 20521, STOP 27.
Medellin	Lawrence V. Blade	U.S. Geological Survey, c/o American Consulate, Medellin, Colombia.
Costa Rica, San José	Frank D. Spencer	U.S. Geological Survey, c/o American Embassy, San José, Costa Rica.
Liberia, Monrovia	Warren L. Coonrad	U.S. Geological Survey, U.S. AID/Monrovia, U.S. Department of State, Washington, D.C. 20521, STOP 27.
Saudi Arabia, Jidda	Glen F. Brown	U.S. Geological Survey, c/o American Embassy, APO New York 09697.

WATER RESOURCES DIVISION

Location	Official in charge	Address
Afghanistan, Kabul	Arthur O. Westfall	U.S. Geological Survey, U.S. AID/Kabul, c/o American Embassy, APO New York 09668.
Kandahar	Vito J. Latkovich	U.S. Geological Survey, U.S. AID/Kabul, c/o American Embassy, APO New York 09668.
Brazil, Recife	Stuart L. Schoff	U.S. AID/Recife, Department of State, Washington, D.C. 20521.
Rio de Janeiro	Floyd F. LeFever	U.S. Geological Survey, U.S. AID/Rio, c/o American Embassy, APO New York 09676.
Egypt, Cairo	Robert L. Cushman	American Embassy, Box 10 FPO New York 09527.
Korea, Seoul	Joseph T. Callahan	USOM/Korea IED-9E, APO San Francisco, Calif. 96301.
Nepal, Katmandu	Woodrow W. Evett	Industry and Mining Div., U.S. AID/Katmandu State Department Mailroom, Washington, D.C. 20521.

Location	Official in charge	Address
Nigeria, Enugu	Elizardo Lucero	U.S. AID/Enugu, c/o American Consulate, Enugu, Nigeria.
Kaduna	David A. Phoenix	Geological Survey of Nigeria, Kaduna South, Northern Nigeria.
Kano	Billy E. Colson	U.S. AID Mission (Kano), c/o American Embassy, Lagos, Nigeria.
Maiduguri	G. C. Tibbitts, Jr	AID/USGS, Geological Survey, Maiduguri, Northern Region, Nigeria.
Sokoto	Henry R. Anderson	U.S. AID/GSN, P.O. Box 93, Sokoto, Northern Nigeria.
Pakistan, Lahore	Maurice J. Mundorff	U.S. AID/L, c/o American Embassy, APO New York 09271.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC, WATER RESOURCES, AND CONSERVATION DIVISIONS

Investigations in progress at the end of fiscal year 1966 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. A217, 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 (g, Ground Water Branch; s, Surface Water Branch; q, Quality of Water Branch); no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity 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:
- Analytical methods—water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (I. May, W; L. F. Rader, Jr., D; R. E. Stevens, M)
- Electron-probe analysis (R. H. Heidel, M)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances—pesticides—in water (W. L. Lamar, w, M)
- Pesticides and insecticides, determination in water (G. Stratton, w, Columbus, Ohio)
- Radioactivation and radiochemistry (F. E. Senftle, W; H. T. Millard, D)
- Radioelements, physical chemistry (K. W. Edwards, w, D)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapiro, W)
- Trace analysis methods:
  - Development (H. W. Lakin, D)
  - Research (F. N. Ward, D)
- Trace analysis service (F. N. Ward, D)
- See also Spectroscopy.

Artificial recharge:
- Idaho, Snake Plain aquifer (R. F. Norvitch, g, Boise)
- New York, treated sewage through an injection well, Bay Park, Long Island (P. Cohen, w, Mineola)
- Oregon, basalt aquifers, Salem Heights and The Dalles (B. L. Foxworthy, g, Portland)
- Texas, Hueco bolson area (E. R. Leggat, w, Austin)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)
- Arizona, Blue House and McFadden Peak quadrangles (A. F. Shride, D)
- Vermont, north-central (W. M. Cady, D)

Barite:
- Arkansas (D. A. Brobst, D)

Base metals:
- Colorado:
  - Kokomo and Tenmile Range mining district (M. H. Bergendahl, D)
  - Wet Mountains (M. R. Brock, D)
- Montana, Philipsburg area (W. C. Prinz, W)
- Utah, San Francisco Mountains (D. M. Lemmon, M)
- See also base-metal names.

Bauxite:
- Southeastern United States (E. F. Overstreet, W)
- Hawaii, Kauai (S. H. Patterson, W)

Beryllium:
- Western United States, volcanic and associated rocks (D. R. Shawe, D)
- Alaska, Lost River mining district (C. L. Sainsbury, D)
- Colorado:
  - Lake George district (C. C. Hawley, D)
  - Mt. Antero (W. N. Sharp, D)
- Nevada, Mt. Wheeler mine area (D. E. Lee, D)

Bibliographies and abstracts:
- Alaskan geology, index of literature (E. H. Cobb, M)
- Arid-land hydrology, bibliography, (S. E. Rantz, w, M)
- Geochemical exploration abstracts (C. B. Davidson, D)
- Geophysical abstracts (J. W. Clarke, W)
- Hydrology of the United States, bibliography (J. R. Randolph, w, W)
- Lunar bibliography (J. H. Freeberg, M)
- North American geology, abstracts (J. W. Clarke, W)
- North American geology, bibliography (J. W. Clarke, W)
- Vanadium, geology and resources, bibliography (J. P. Ohl, D)

Earthquake studies--Continued
  California--Continued
    Geophysical studies, San Andreas fault (J. H. Healy, D)
    Regional tectonic analysis (R. E. Wallace, M)
    Precambrian rocks along San Andreas fault (D. C. Ross, M)
    Volcanic rocks near San Andreas fault (D. C. Ross, M)
  Hazard analysis:
    Anchorage, Alaska (E. Dobrovolny, D)
    Juneau, Alaska (R. D. Miller, D)
    Small coastal communities (R. W. Lemke, D)
Engineering geologic studies. See Construction and terrain problems; Urban geology.
Evaporation:
  Evaporation from lakes and reservoirs (J. S. Meyers, w, D)
  Arizona, theory and measurement (O. E. Leppanen, w, Phoenix)
  Indiana, evaporation losses from lakes (R. E. Hoggatt, w, Indianapolis)
  Louisiana, pond-evaporation study (F. N. Lee, s, Baton Rouge)
  North Carolina, Hyco River basin, evaporation and thermal-loading analysis (J. F. Turner, w, Raleigh)
  See also Hydrologic instrumentation.
Evaporation suppression:
  Mechanics of evaporation suppression and evaporation (G. E. Koberg, w, D)
Evapotranspiration:
  Hydrologic effects of vegetation modification (R. M. Myrick, w, Tucson, Ariz.)
  Phreatophytes and their effect on the hydrologic regimen (T. W. Robinson, w, M)
  Use of water by saltcedar in evapotranspirometers (T. E. A. van Hylckama, w, Buckeye, Ariz.)
  Arizona:
    Effect of removing riparian vegetation, Cottonwood Wash (J. E. Bowie, w, Tucson)
    Phreatophyte project, Gila River (R. C. Culler, w, Tucson)
    Study of effects of vegetation manipulation on surface runoff, Sycamore Creek (H. W. Hjalmarson, w, Phoenix)
  California:
    Comparison of methods of calculating evapotranspiration, using climatic data (R. W. Cruff, w, M)
    Root-zone conditions and plant-physiological processes as factors in evapotranspiration, Imperial Camp (R. E. Felch, w, Yuma, Ariz.)
  New Jersey, interception and evapotranspiration of a forest-floor shrub layer (E. C. Rhodehamel, W. A. Reiners, g, Trenton)
Extraterrestrial studies:
  Astronaut training program (A. H. Chidester, Flagstaff, Ariz.)
  Cratering and impact investigations:
    Experimental impact investigations (H. J. Moore II, M)
    Flynn Creek, Tenn., crater studies (D. J. Roddy, Pasadena, Calif.)
    Impact metamorphism (E. C. T. Chao, W)
    Investigation of maars (H. Masursky, M)

Extraterrestrial studies--Continued
  Cratering and impact investigations--Continued
    Investigation of missile impacts at White Sands, N. Mex. (H. J. Moore II, M)
    Shock effects, San Andreas fault, California (C. H. Roach, D)
    Shock phase studies (D. J. Milton, M)
    Sierra Madera, Tex., crater studies (H. G. Wilshire, D)
    Solid-state investigations of craters (C. H. Roach, D)
    Terrestrial impact structures (D. J. Milton, M)
  Experimental studies:
    Apollo seismic experiment (J. S. Watkins, Jr., Flagstaff, Ariz.)
    Data reduction systems for Apollo application missions (G. A. Swann, Flagstaff, Ariz.)
    Development of geological and geophysical methods and instruments for advanced systems (J. T. O'Connor, Flagstaff, Ariz.)
    Development of geological and geophysical methods and instruments for Apollo application missions (G. A. Swann, Flagstaff, Ariz.)
    Development of geological methods and instruments for early Apollo flights (J. W. M'Gonigle, Flagstaff, Ariz.)
    Early Apollo photometry and photogrammetry (H. E. Holt, Flagstaff, Ariz.)
    Experimental photometric investigations (H. E. Holt, Flagstaff, Ariz.)
    Image filtering studies (R. L. Wildey, Flagstaff, Ariz.)
    In situ field geophysics operations (H. D. Ackermann, Flagstaff, Ariz.)
    In situ geologic studies (L. A. Walters, Flagstaff, Ariz.)
    In situ seismic theory (J. H. Whitcomb, Flagstaff, Ariz.)
    Investigation of the lunar photometric function (R. L. Wildey, Flagstaff, Ariz.)
    Lunar infrared investigations (K. Watson, Flagstaff, Ariz.)
    Lunar polarimetry (R. L. Wildey, Flagstaff, Ariz.)
    Manned lunar exploration mission planning (H. Masursky, M)
    Nuclear cavity detection (R. H. Godson, Flagstaff, Ariz.)
    Occultation investigations of the lunar limb (K. Watson, Flagstaff, Ariz.)
    Orbiter photoclinometry (M. J. Grolier, Flagstaff, Ariz.)
    Orbiter photogrammetric studies (W. T. Borgeson, Flagstaff, Ariz.)
    Orbiter site-evaluation studies (L. C. Rowan, Flagstaff, Ariz.)
    Orbiter systems analysis (E. F. Kiernan, Flagstaff, Ariz.)
    Ranger photoclinometry (L. C. Rowan, Flagstaff, Ariz.)
    Ranger photogrammetry (J. D. Alderman, Flagstaff, Ariz.)
    Surveyor electronics (E. C. Morris, Flagstaff, Ariz.)
    Surveyor photogrammetry (R. M. Batson, Flagstaff, Ariz.)
    Surveyor photometry and optics (E. C. Morris, Flagstaff, Ariz.)

Geochemistry and petrology, field studies--Continued
- Montana:
  - Bearpaw Mountains, petrology (W. T. Pecora, W)
  - Boulder batholith, petrochemistry (R. I. Tilling, W)
  - Stillwater complex, petrology and chromite resources (E. D. Jackson, M)
  - Wolf Creek area, petrology (R. G. Schmidt, W)
- New Mexico:
  - Grants area, mineralogy of uranium-bearing rocks (A. D. Weeks, W)
  - Valles Mountains (R. L. Smith, W)
- New York, Gouverneur area, metamorphism and origin of mineral deposits (A. E. J. Engel, La Jolla, Calif.)
- South Carolina, igneous and metamorphic rocks of the piedmont (W. C. Overstreet, Jidda, Saudi Arabia)
- Texas, Duval and Karnes Counties, mineralogy of uranium-bearing rocks (A. D. Weeks, W)
- Wisconsin, geochemical survey of the Driftless area (H. T. Shacklette, D)
- Wyoming:
  - Green River Formation, geology and paleolimnology (W. H. Bradley, W)
  - Yellowstone National Park, thermal waters (D. E. White, M)

Geochronology:
- Carbon-14 method (M. Rubin, W)
- Conifers, factors governing growth on Sunset Crater, Ariz. (L. Horner, D. O'Bryan, w, W)
- Geologic time scale (R. E. Zartman, D)
- Igneous rocks and deformational periods (R. W. Kistler, M)
- Lead-uranium method (T. W. Stern, W)
- Long-term chronologies of hydrologic events (W. D. Simons, w, Tacoma, Wash.)
- Post-Pleistocene epicycle sequence of alluviation and erosion in the lower San Juan drainage, Navajo and Apache Counties, Ariz. (D. O'Bryan, M. E. Cooley, w, W)
- Potassium-argon and rubidium-strontium methods (M. A. Lanphere, M; Z. E. Peterman, D)
- Radioactive-disequilibrium studies (J. N. Rosholt, D)
- Tree growth, influence of prolonged drought (1961–) in mid-Atlantic States (D. O'Bryan, L. Horner, w, W)
- Tree growth as a record of moisture availability in the Southwest (D. O'Bryan, N. C. Matalas, L. Horner, w, W)
- Tree-growth trend function, definition (N. C. Matalas, L. Horner, w, W)
- Tree-ring indices, general statistical properties of sequences (N. C. Matalas, L. Horner, w, W)
- Alaska, southeastern part (G. D. Eberlein, M. A. Lanphere, M)
- <u>See also</u> Isotope and nuclear studies.

Geologic mapping:
- Map scale smaller than 1 inch to 1 mile:
  - Colorado Plateau:
    - Geologic maps (2-minute sheets) (D. G. Wyant, D)
    - Photogeologic mapping (A. B. Olson, W)
  - Sino-Soviet Terrain Atlas (M. M. Elias, W)
  - Alaska:
    - Compilation of geologic maps, 1:250,000 quadrangles (G. Gryc, M)

Geologic mapping--Continued
- Map scale smaller than 1 inch to 1 mile--Continued
  - Alaska--Continued
    - Geologic map of State (G. O. Gates, M)
    - Metallogenic map (C. L. Sainsbury, D)
    - Central and northern part, Cenozoic (D. M. Hopkins, M)
    - Northern part, petroleum investigations (G. Gryc, M)
    - Brooks Range, southern part (W. P. Brosgé, M)
    - Buckland River area (W. W. Patton, Jr., M)
    - Charley River quadrangle (E. E. Brabb, M)
    - Delong Mountains quadrangle (I. L. Tailleur, M)
    - Fairbanks quadrangle (F. R. Weber, College)
    - Hughes-Shungnak area (W. W. Patton, Jr., M)
    - Huslia River area (W. W. Patton, Jr., M)
    - Iliamna quadrangle (R. L. Detterman, M)
    - Klukwan iron district (E. C. Robertson, W)
    - Livengood quadrangle (B. Taber, M)
    - Lower Yukon-Koyukuk area (W. W. Patton, Jr., M)
    - Lower Yukon-Norton Sound region (J. M. Hoare, M)
    - Nelchina area (A. Grantz, M)
    - Point Hope quadrangle (I. L. Tailleur, M)
    - Yukon-Koyukuk lowland, engineering geology (F. R. Weber, College)
  - Antarctica:
    - Western part, reconnaissance geology (E. L. Boudette, W)
    - Eights and Walgreen Coasts, reconnaissance geology (A. A. Drake, Jr., W)
    - Victoria Land, northeastern part (W. B. Hamilton, D)
  - California, San Raphael Primitive Area (H. D. Gower, M)
  - Colorado:
    - Oil-shale investigations (D. C. Duncan, W)
    - Durango 2-degree quadrangle (T. A. Steven, D)
    - Grand Junction 2-degree quadrangle (W. B. Cashion, D)
    - La Junta 2-degree quadrangle (G. R. Scott, D)
    - Lamar 2-degree quadrangle (G. R. Scott, D)
    - Pueblo 2-degree quadrangle (G. R. Scott, D)
    - Trinidad 2-degree quadrangle (R. B. Johnson, D)
  - Idaho:
    - Preston 2-degree quadrangle (S. S. Oriel, D)
    - Snake River plain, central part, volcanic petrology (H. E. Malde, D)
    - Spokane-Wallace region (A. B. Griggs, M)
  - Montana:
    - Butte 2-degree quadrangle (M. R. Klepper, W)
    - Spokane-Wallace region (A. B. Griggs, M)
  - Nevada:
    - Churchill County (C. R. Willden, M)
    - Douglas County (J. G. Moore, M)
    - Esmeralda County (J. P. Albers, M)
    - Eureka County (R. J. Roberts, M)
    - Lincoln County (C. M. Tschanz, La Paz, Bolivia)
    - Lyon County (J. G. Moore, M)
    - Nevada Test Site, reconnaissance (F. N. Houser, D)
    - Nye County:
      - Northern part (F. J. Kleinhampl, M)
      - Southern part (H. R. Cornwall, M)

Geologic mapping--Continued
Map scale 1 inch to 1 mile and larger--Continued
Colorado:
Air Force Academy (D. J. Varnes, D)
Animas River area (H. Barnes, D)
Aspen quadrangle (B. Bryant, D)
Baggs area (G. E. Prichard, D)
Berthoud Pass quadrangle (P. K. Theobald, D)
Black Canyon of the Gunnison River (W. R. Hansen, D)
Black Hawk quadrangle (R. B. Taylor, D)
Bonanza quadrangle (R. E. Van Alstine, W)
Bottle Pass quadrangle (R. B. Taylor, D)
Boulder quadrangle (C. T. Wrucke, D)
Bull Canyon district (C. H. Roach, D)
Cameron Mountain quadrangle (C. T. Wrucke, D)
Carbondale coal field (J. R. Donnell, D)
Cheyenne Mountain, electrical properties (J. H. Scott, D)
Corral Bluffs quadrangle (P. E. Soister, c, D)
Creede district (T. A. Steven, D)
Denver metropolitan area (R. M. Lindvall, D)
East Portal quadrangle (P. K. Theobald, D)
Eldorado Springs quadrangle (J. D. Wells, D)
Elk Aprings quadrangle (J. R. Dyni, c, D)
Empire quadrangle (W. A. Braddock, Boulder)
Evergreen quadrangle (D. M. Sheridan, D)
Fraser quadrangle (P. K. Theobald, D)
Front Range:
East-central part, mountain front area (D. M. Sheridan, D)
Northeastern part, Fort Collins area (W. A. Braddock, Boulder)
Golden quadrangle (R. Van Horn, D)
Grand-Battlement Mesa (J. R. Donnell, D)
Hanover NW quadrangle (P. E. Soister, c, D)
Holy Cross quadrangle (O. Tweto, W)
Indian Hills quadrangle (D. M. Sheridan, D)
Kokomo mining district (M. H. Bergendahl, D)
Kremmling quadrangle (G. A. Izett, c, D)
Lafayette quadrangle (K. B. Ketner, D)
Lake George district (C. C. Hawley, D)
Lisbon Valley area (G. W. Weir, Berea, Ky.)
Maybell-Lay area (M. J. Bergin, W)
Montrose 1 SE, 1 SW, and 4 NE quadrangles (R. G. Dickinson, c, D)
Morrison quadrangle (D. J. Gable, D)
Mt. Antero (W. N. Sharp, D)
Mt. Harvard quadrangle (M. R. Brock, D)
Nederland quadrangle (D. J. Gable, D)
Niwot quadrangle (M. McLachlan, D)
North Park:
Eastern part (D. M. Kinney, W)
Western part (W. J. Hail, D)
Oh-Be-Joyful quadrangle (D. L. Gaskill, c, D)
Park Range, northern part (G. L. Snyder, D)
Peoria quadrangle (P. E. Soister, c, D)
Placita SE quadrangle (L. H. Godwin, c, D)
Poncha Springs quadrangle (R. E. Van Alstine, W)
Powderhorn area (J. C. Olson, D)
Pueblo and vicinity (G. R. Scott, D)
Ralston Buttes (D. M. Sheridan, D)
Rangely 3 quadrangle (H. L. Cullins, c, D)
Rico district (E. T. McKnight, W)
Rico-Animas area (W. P. Pratt, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Colorado--Continued
Ruedie quadrangle (V. L. Freeman, D)
San Juan mining area (R. G. Luedke, W)
San Juan Mountains, western (A. L. Bush, D)
Slick Rock district (D. R. Shawe, D)
Squaw Pass quadrangle (D. M. Sheridan, D)
Straight Creek tunnel (F. T. Lee, D)
Tenmile Range (M. H. Bergendahl, D)
Tungsten quadrangle (D. J. Gable, D)
Wet Mountains (M. R. Brock, D)
Woody Creek quadrangle (V. L. Freeman, D)
Connecticut:
Taconic sequence (E-an Zen, W)
Ashaway quadrangle:
Bedrock geology (T. G. Feininger, Boston, Mass.)
Surficial geology (J. P. Schafer, Boston, Mass.)
Ashley Falls quadrangle, surficial geology (G. W. Holmes, W)
Bristol quadrangle, bedrock geology (H. E. Simpson, D)
Columbia quadrangle, bedrock geology (G. L. Snyder, D)
Cornwall quadrangle, surficial geology (R. B. Colton, D)
Danielson quadrangle:
Bedrock geology (H. R. Dixon, Boston, Mass.)
Surficial geology (A. D. Randall, Albany, N.Y.; F. Pessl, Jr., Boston, Mass.)
Durham quadrangle (H. E. Simpson, D)
East Killingly quadrangle, bedrock geology (G. E. Moore, Columbus, Ohio)
Eastford quadrangle (M. H. Pease, Boston, Mass.)
Litchfield quadrangle, surficial geology (C. E. Warren, W)
Marlborough quadrangle, bedrock geology (G. L. Snyder, D)
Meriden quadrangle, bedrock geology (P. M. Hanshaw, Boston, Mass.)
Middle Haddam quadrangle, bedrock geology (G. P. Eaton, Pasadena, Calif.)
Montville quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
Mystic quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
New Hartford quadrangle (R. W. Schnabel, D)
New London quadrangle (R. Goldsmith, Boston, Mass.)
New Preston quadrangle, surficial geology (R. B. Colton, D)
Niantic quadrangle (R. Goldsmith, Boston, Mass.)
Norwalk South quadrangle, surficial geology (H. E. Malde, D)
Old Mystic quadrangle (R. Goldsmith, Boston, Mass.)
Oneco quadrangle (R. Goldsmith, Boston, Mass.)
Plainfield quadrangle, surficial geology (A. D. Randall, g, Albany, N.Y.)
Putnam quadrangle, bedrock geology (H. R. Dixon, D)
Roxbury quadrangle, surficial geology (H. E. Malde, D)
Southbury quadrangle, surficial geology (F. Pessl, Jr., Boston, Mass.)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Connecticut--Continued
Southwick quadrangle (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston, Mass.)
Tariffville quadrangle, surficial geology (A. D. Randall, g, Binghamton, N.Y.)
Thompson quadrangle (P. M. Hanshaw, Boston, Mass., H. R. Dixon, D)
Tolland Center quadrangle, construction materials (G. W. Holmes, W)
Torrington quadrangle, surficial geology (R. B. Colton, D)
Uncasville quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
Watch Hill quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Waterbury quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
West Granville quadrangle, construction materials (G. W. Holmes, W)
West Springfield quadrangle (R. B. Colton, J. H. Hartshorn, Boston, Mass.)
West Torrington quadrangle, surficial geology (R. W. Colton, D)
Woodbury quadrangle, surficial geology (F. Pessl, Jr., Boston, Mass.)
District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)
Florida:
Land-pebble phosphate deposits (J. B. Cathcart, D)
Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Georgia:
Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Brevard Belt, crystalline rocks (M. Higgins, Atlanta)
Greenland, Schuchert Dal, East Greenland, glacial geology (J. S. Hartshorn, Boston, Mass.)
Idaho:
Central part, radioactive placer deposits (D. L. Schmidt, W)
American Falls region (D. E. Trimble, D)
Aspen Range-Dry Ridge area (V. E. McKelvey, W)
Bancroft quadrangle (S. S. Oriel, D)
Bayhorse area (S. W. Hobbs, D)
Big Creek quadrangle (B. F. Leonard, D)
Driggs NE, SE, and SW quadrangles (M. L. Schroeder, c, D)
Elmira quadrangle (J. E. Harrison, W)
Greenacres quadrangle (P. L. Weis, Spokane, Wash.)
Hawley Mountain quadrangle (W. J. Mapel, D)
Leadore quadrangle (E. T. Ruppel, D)
Mackay quadrangle (W. H. Nelson, M)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Mountain City quadrangle (R. R. Coats, M)
Orofino area (A. Hietanen-Makela, M)
Owyhee quadrangle (R. R. Coats, M)
Patterson quadrangle (E. T. Ruppel, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Idaho--Continued
Pocatello quadrangle (D. E. Trimble, D)
Riggins quadrangle (W. B. Hamilton, D)
Soda Springs quadrangle (F. C. Armstrong, D)
Upper Valley quadrangle (R. L. Rioux, c, W)
Yandell Springs quadrangle (D. E. Trimble, D)
Yellow Pine quadrangle (B. F. Leonard, D)
Indiana, Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Kansas:
Shawnee County (W. D. Johnson, Jr., Owensboro, Ky.)
Wilson County (H. C. Wagner, M)
Kentucky:
Note: The entire State of Kentucky is being mapped geologically by 7½ minute quadrangles under a cooperative program with the Kentucky Geological Survey. 208 quadrangles have been published and 178 more are currently in progress. Project is under the supervision of P. W. Richards, Lexington, Ky. The following investigations are separate from the cooperative mapping program:

Eastern part, coal investigations (K. J. Englund, W)
Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Jellico West quadrangle (K. J. Englund, W)
Ketchen quadrangle (K. J. Englund, W)
Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Maine:
Paleozoic stratigraphy, regional (R. B. Neuman, W)
Aroostook County, southern (L. Pavlides, W)
Attean quadrangle (A. L. Albee, Pasadena, Calif.)
Greenville quadrangle (G. H. Espenshade, W)
Kennebago Lake and Cupsuptic quadrangles (E. L. Boudette, W; D. S. Harwood, Boston, Mass.)
Moosehead gabbro (G. H. Espenshade, W)
Rangeley quadrangle (R. H. Moench, D)
Rumford quadrangle (R. H. Moench, D)
Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
The Forks quadrangle (F. C. Canney, E. V. Post, D)
Maryland:
Chesapeake Bay area, upper part (J. P. Minard, W)
Harford County (D. Southwick, W)
Washington, D. C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Massachusetts:
Taconic sequence (E-an Zen, W)
Ashley Falls quadrangle, surficial geology (G. W. Holmes, W)
Athol quadrangle (D. F. Eschman, Ann Arbor, Mich.)
Becket quadrangle, construction materials (G. W. Holmes, W)
Billerica quadrangle (R. H. Jahns, University Park, Pa.)
Blandford quadrangle, construction materials (G. W. Holmes, W)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Massachusetts--Continued
Blue Hills quadrangle (N. E. Chute, Syracuse, N.Y.)
Boston and vicinity (C. A. Kaye, Boston)
Boston North quadrangle, bedrock geology (K. G. Bell, D)
Chatham quadrangle (R. N. Oldale, Boston)
Cheshire quadrangle, construction materials (G. W. Holmes, W)
Chester quadrangle, construction materials (G. W. Holmes, W)
Clinton quadrangle:
Bedrock geology (R. F. Novotny, Boston)
Surficial geology (C. Koteff, Boston)
Concord quadrangle (N. P. Cuppels, Boston)
East Lee quadrangle, construction materials (G. W. Holmes, W)
Egremont quadrangle, bedrock geology (E-an Zen, W; N. M. Ratcliffe, Boston)
Georgetown quadrangle (N. P. Cuppels, Boston)
Great Barrington quadrangle, bedrock geology (E-an Zen, W; N. M. Ratcliffe, Boston)
Greenfield quadrangle, surficial geology (R. H. Jahns, Palo Alto, Calif.)
Hancock quadrangle, construction materials (G. W. Holmes, W)
Harwich quadrangle (R. N. Oldale, Boston)
Heath quadrangle (A. H. Chidester, D; J. H. Hartshorn, Boston)
Hull quadrangle, bedrock geology (K. G. Bell, D)
Lawrence quadrangle, bedrock geology (R. O. Castle, M)
Lowell quadrangle (R. H. Jahns, Palo Alto, Calif.)
Lynn quadrangle, bedrock geology (K. G. Bell, D)
Marblehead South quadrangle, bedrock geology (K. G. Bell, D)
Monomoy Point quadrangle (C. Koteff, R. N. Oldale, J. N. Hartshorn, Boston)
Nantasket quadrangle, bedrock geology (K. G. Bell, D)
North Adams quadrangle, construction materials (G. W. Holmes, W)
North Truro quadrangle (C. Koteff, R. N. Oldale, J. H. Hartshorn, Boston)
Norwood quadrangle (N. E. Chute, Syracuse, N.Y.)
Orleans quadrangle (R. N. Oldale, Boston)
Peru quadrangle, construction materials (G. W. Holmes, W)
Pittsfield East quadrangle, construction materials (G. W. Holmes, W)
Plainfield quadrangle:
Bedrock geology (P. H. Osberg, Orono, Maine)
Construction materials (G. W. Holmes, W)
Reading quadrangle, bedrock geology (R. O. Castle, M)
Rowe quadrangle (A. H. Chidester, D; J. H. Hartshorn, Boston)
Shrewsbury quadrangle, bedrock geology (R. F. Novotny, Boston)
South Groveland quadrangle, bedrock geology (R. O. Castle, M)
Southwick quadrangle (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston)
Taunton quadrangle (J. H. Hartshorn, Boston)
Tolland Center quadrangle, construction materials (G. W. Holmes, W)
Tyngsboro quadrangle (R. H. Jahns, Palo Alto, Calif.)
Wellfleet quadrangle (R. N. Oldale, Boston)
West Granville quadrangle, construction materials (G. W. Holmes, W)
West Springfield quadrangle (R. B. Colton, D; J. H. Hartshorn, Boston)
Westford quadrangle (R. H. Jahns, Palo Alto, Calif.)
Williamstown quadrangle, construction materials (G. W. Holmes, W)
Wilmington quadrangle, bedrock geology (R. O. Castle, M)
Windsor quadrangle, bedrock geology (S. A. Norton, Boston)
Worthington quadrangle, construction materials (G. W. Holmes, W)
Michigan:
Dickinson County, southern (R. W. Bayley, M)
Gogebic Range, eastern (W. C. Prinz, W)
Iron County, eastern (K. L. Wier, D)
Iron River–Crystal Falls district (H. L. James, W)
Marenisco-Watersmeet area, iron deposits (C. E. Fritts, D)
Marquette district, eastern (J. E. Gair, Marquette)
Negaunee quadrangle (J. E. Gair, Marquette)
Palmer quadrangle (J. E. Gair, Marquette)
Mississippi:
Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)
Tatum salt dome (W. E. Hale, D)
Missouri, Lesterville quadrangle (T. H. Kiilsgaard, W)
Montana:
Southwestern part, ore deposits (K. L. Wier, D)
Alberton quadrangle (J. D. Wells, W)
Barker quadrangle (I. J. Witkind, D)
Bearpaw Mountains, petrology (W. T. Pecora, W)
Black Butte quadrangle (A. F. Bateman, Jr., c, Great Falls)
Black Mountains quadrangle (L. W. McGrew, Laramie, Wyo.)
Boulder batholith area (M. R. Klepper, W)
Browning area, Quaternary geology (G. M. Richmond, D)
Cameron quadrangle (J. B. Hadley, W)
Crazy Mountains Basin (B. A. Skipp, D)
Gardiner SW quadrangle (G. D. Fraser, c, D)
Girard coal field (G. E. Prichard, D)
Great Falls area (R. W. Lemke, D)
Hardy quadrangle (K. S. Soward, c, Great Falls)
Holter Lake quadrangle (G. D. Robinson, D)
Jordan (30-minute) quadrangle (G. D. Mowat, c, Great Falls)
Livingston–Trail Creek area (A. E. Roberts, D)
Maudlow quadrangle (B. A. Skipp, D)
Montaqua quadrangle (E. D. Patterson, c, W)
Neihart 1 quadrangle (W. R. Keefer, D)

Geologic mapping--Continued
- Map scale 1 inch to 1 mile, and larger--Continued
  - Oklahoma, Ft. Smith district (T. A. Hendricks, D)
  - Oregon:
    - Bandon SE quadrangle (R. G. Wayland, c, Los Angeles, Calif.)
    - Coquille SW quadrangle (R. G. Wayland, c, Los Angeles, Calif.)
    - Loomis quadrangle (C. D. Rinehart, M)
    - Monument quadrangle (R. E. Wilcox, D)
    - Newport Embayment (P. D. Snavely, Jr., M)
  - Pacific Islands:
    - Bikini and nearby atolls (H. S. Ladd, W)
    - Pacific Islands, vegetation (F. R. Fosberg, W)
    - Western Pacific islands (G. Corwin, W)
  - Pennsylvania:
    - Anthracite mine-drainage projects, geology in the vicinity of (G. H. Wood, Jr., W)
    - Anthracite region, flood control (M. J. Bergin, W)
    - Bituminous coal resources (E. D. Pattersen, W)
    - Devonian stratigraphy of State (G. W. Colton, W)
    - Allentown Northeast quadrangle (J. M. Aaron, W)
    - Claysville-Avella area (S. P. Schweinfurth, D)
    - Delaware River basin:
      - Lower part (J. P. Owens, W)
      - Middle part (A. A. Drake, Jr., W)
    - Mather-Garards Fort area (B. H. Kent, D)
    - Philadelphia district, Lower Cambrian (J. H. Wallace, W)
    - Shenango quadrangle, Mercer County (G. R. Schiner, g, Harrisburg)
    - Southern anthracite field (G. H. Wood, Jr., W)
    - Stoneboro quadrangle, Mercer County (G. R. Schiner, g, Harrisburg)
    - Waynesburg-Oak Forest area (J. B. Roen, W)
    - Western Middle anthracite field (H. Arndt, W)
    - Wind Gap and adjacent quadrangles (J. B. Epstein, W)
  - Puerto Rico (R. P. Briggs, San Juan)
  - Rhode Island:
    - Ashaway quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
    - Carolina quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
    - Chepachet quadrangle, bedrock geology (A. W. Quinn, Providence)
    - Clayville quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
    - Coventry Center quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
    - East Killingly quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
    - Newport quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
    - Oneco quadrangle (R. Goldsmith, Boston, Mass.)
    - Prudence Island quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
    - Quonochontaug quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
    - Thompson quadrangle (H. R. Dixon, D; P. M. Hanshaw, Boston, Mass.)
    - Watch Hill quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
  - South Dakota:
    - Black Hills, southern (G. B. Gott, D)
    - Fort Randall Reservoir area (D. J. Varnes, D)

Geologic mapping--Continued
- Map scale 1 inch to 1 mile, and larger--Continued
  - South Dakota--Continued
    - Four Corners quadrangle (J. A. Van Lieu, Laramie, Wyo.)
    - Harding County and adjacent areas (G. W. Pipiringos, D)
    - Hill City pegmatite area (J. C. Ratté, D)
    - Keystone pegmatite area (J. J. Norton, W)
    - Rapid City area (E. Dobrovolny, D)
  - Tennessee:
    - Appalachian folded belt, southern part (L. D. Harris, W)
    - Great Smoky Mountains (J. B. Hadley, W)
    - Ivydell quadrangle (K. J. Englund, W)
    - Jellico West quadrangle (K. J. Englund, W)
    - Ketchen quadrangle (K. J. Englund, W)
    - Midway belt, western part of State (W. S. Parkes, w, Nashville)
    - Pioneer quadrangle (K. J. Englund, W)
  - Texas:
    - Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
    - North-central part, Pennsylvanian Fusulinidae (D. A. Myers, D)
    - Del Rio area (V. L. Freeman, D)
    - Franklin Mountains (R. L. Harbour, D)
  - Utah:
    - Coal-mine bumps (F. W. Osterwald, D)
    - Alta quadrangle (M. D. Crittenden, Jr., M)
    - Bingham Canyon district (R. J. Roberts, M)
    - Causey Dam quadrangle (T. E. Mullens, c, D)
    - Circle Cliffs area (E. S. Davidson, Tucson, Ariz.)
    - Confusion Range (R. K. Hose, M)
    - Crawford Mountains (W. C. Gere, c, D)
    - Cummings Mesa quadrangle (F. Peterson, c, D)
    - Garrison quadrangle (D. H. Whitebread, M)
    - Gilbert Peak 1 NE quadrangle (J. R. Dyni, c, D)
    - Griffin Point quadrangle (W. E. Bowers, c, D)
    - Gunsight Butte quadrangle (F. Peterson, c, D)
    - Hurricane fault, southwestern Utah (P. Averitt, D)
    - Jessen Butte quadrangle (J. R. Dyni, c, D)
    - Kaiparowits Peak 4 quadrangle (H. D. Zeller, c, D)
    - Kolob Terrace coal field, southern part (W. B. Cashion, D)
    - Lehi quadrangle (M. D. Crittenden, Jr., M)
    - Lisbon Valley area (G. W. Weir, Berea, Ky.)
    - Moab-Interriver area (E. N. Hinrichs, D)
    - Morgan quadrangle (T. E. Mullens, c, D)
    - Navajo Reservation (R. B. O'Sullivan, D)
    - Nipple Butte quadrangle (H. A. Waldrop, c, D)
    - Oak City area (D. J. Varnes, D)
    - Ogden 4 NE quadrangle (T. E. Mullens, c, D)
    - Ogden 4 NW quadrangle (R. J. Hite, c, D)
    - Orange Cliffs area (F. A. McKeown, D)
    - Park City area (M. D. Crittenden, Jr., M)
    - Part City district (C. S. Bromfield, D)
    - Phil Pico Mountain quadrangle (J. R. Dyni, c, D)
    - Promontory Point (R. B. Morrison, D)
    - Salt Lake City and vicinity (R. Van Horn, D)
    - San Francisco Mountains (D. M. Lemmon, M)
    - San Rafael Swell (C. C. Hawley, D)
    - Sheeprock Mountains, West Tintic district (H. T. Morris, M)
    - Snake Range, Wheeler Peak and Garrison quadrangles (D. H. Whitebread, M)

Geomorphology--Continued
- Relation of drainage networks and basin development to rock type and climate (R. F. Hadley, w, D)
- Slope morphology, effect of exposure (R. F. Hadley, w, D)
- Soil creep, mechanisms (R. L. Schiffman, w, Troy, N.Y.)
- Stream morphology and processes (R. K. Fahnestock, w, D)
- Colorado River, geologic history (C. B. Hunt, w, Baltimore, Md.)
- Ohio River valley, geologic development (L. L. Ray, W)
- Alabama, Russell Cave (J. T. Hack, W)
- Arizona, process, landform, and vegetation in a semiarid area: The San Pedro Valley (R. C. Zimmerman, w, Johns Hopkins Univ., Baltimore, Md.)
- California:
  - Rates of land denudation (V. C. LaMarche, Jr., w, M)
  - Sierra Nevada, geomorphic studies (R. J. Janda, w, M)
  - Test of dynamic equilibrium on alluvial fans in Death Valley (L. K. Lustig, w, Tucson, Ariz.)
- Indiana, channel-meander studies (J. F. Daniel, w, Indianapolis)
- Maryland, Potomac River, geomorphic aspects of the Sisters and Watts Branches (L. B. Leopold, w, W)
- Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)
- Montana, Browning area, Quaternary geology (G. M. Richmond, D)
- New Mexico, Santa Fe, particle movement and channel scour and fill of an ephemeral arroyo (L. B. Leopold, w, W)
- New York, northeast Adirondacks (C. S. Denny, W)
- North Carolina, Morganton area (J. T. Hack, W)
- Wyoming:
  - Wind River Mountains, Quaternary geology (G. M. Richmond, D)
  - Yellowstone National Park, glacial and postglacial geology (G. M. Richmond, D)
- <u>See also</u> Geochronology; Sedimentation.

Geophysics, regional:
- Aeroradioactivity surveys:
  - Northeastern United States (J. A. Pitkin, W)
  - California:
    - San Andreas fault (J. H. Healy, D)
    - San Francisco (J. A. Pitkin, W)
  - Colorado, Rocky Flats (J. A. MacKallor, W)
  - Idaho, National Reactor Testing Station (R. G. Bates, W)
  - Maryland, Belvoir area (S. K. Neuschel, W)
  - Minnesota, Elk River (J. A. Pitkin, W)
  - Ohio, Columbus (R. G. Bates, W)
  - Puerto Rico (J. A. Pitkin, W)
  - Texas, Fort Worth (J. A. Pitkin, W)
  - Virginia, Belvoir area (S. K. Neuschel, W)
- Cross-country aeromagnetic profiles (E. R. King, W)
- Crust and upper mantle:
  - Analysis of traveltime data (J. C. Roller, D)
  - Geophysical studies (J. H. Healy, D)
  - Gravity surveying (D. J. Stuart, D)
  - Rocky Mountain seismic network (J. P. Eaton, D)
  - Seismic-refraction profiling (W. H. Jackson, D)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)

Geophysics, regional--Continued
- Antarctica, Pensacola Mountains, geophysical studies (J. C. Behrendt, W)
- Arctic, geophysical studies (I. Zietz, W)
- Central United States, aeromagnetic surveys (J. W. Henderson, W)
- Colorado Plateau, regional geophysical studies (J. E. Case, D)
- Colorado Plateau and southern Rocky Mountains, aeromagnetic surveys (J. E. Case, D)
- Eastern Central United States, tectonic patterns (I. Zietz, W)
- Eastern United States, aeromagnetic surveys (R. W. Bromery, W)
- Japan, calderas, aeromagnetic-gravity studies (H. R. Blank, Jr., M)
- Lake Superior region, geophysical studies (G. D. Bath, M)
- New England, geophysical studies (R. W. Bromery, W)
- Northeastern United States, gravity study (G. Simmons, Dallas, Tex.)
- Pacific Northwest:
  - Aeromagnetic surveys (W. E. Davis, M)
  - Geophysical studies (W. E. Davis, M)
- Pacific Ocean, geophysical studies (D. F. Barnes, M)
- Pacific Southwest:
  - Aeromagnetic surveys (D. R. Mabey, D)
  - Geophysical studies (D. R. Mabey, D)
- Pacific States, geophysical studies (A. Griscom, M)
- Yellowstone National Park, geophysical study (H. R. Blank, M)
- Alaska:
  - Aeromagnetic surveys (G. E. Andreasen, W)
  - Regional gravity surveys (D. F. Barnes, M)
- Arizona:
  - Central part, geophysical study (D. R. Babey, D)
  - Safford Valley, geophysical studies (G. E. Andreasen, W)
  - Tombstone region, geophysical studies (G. E. Andreasen, W)
- California:
  - Los Angeles basin, gravity study (T. H. McCulloh, Riverside)
  - San Francisco Bay area, geophysical studies (G. D. Bath, M)
  - Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Colorado:
  - Arkansas Valley, geophysical study (J. E. Case, D)
  - Middle Park-North Park basins, geophysical studies (J. C. Behrendt, D)
  - Uncompahgre uplift, northwest portion, geophysical studies and geologic mapping (J. E. Case, D)
- District of Columbia, Eastern Piedmont, geophysical studies (S. K. Neuschel, W)
- Idaho, Snake River Plain, geophysical studies (D. R. Mabey, D)
- Iowa, central, aeromagnetic survey (J. R. Henderson, W)
- Maine:
  - Island Falls quadrangle, electromagnetic mapping (F. C. Frischknecht, W)
  - Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
- Massachusetts:
  - Application of geology and seismology to public-works planning (C. R. Tuttle, R. N. Oldale, Boston)

Ground water—surface water relations--Continued
Washington:
Cedar River loss study, surface and ground water (F. T. Hidaka, w, Tacoma)
Columbia River basin, relation of ground-water storage and streamflow (M. I. Rorabaugh, w, Tacoma)
Wisconsin:
Central Sand Plains, hydrology (E. P. Weeks, g, H. G. Stangland, s, Madison)
Wetlands, hydrology (L. J. Hamilton, g, Madison)
Hydraulics, ground water:
Applicability of the unsaturated flow theory to the phenomena of drainage and infiltration (J. Rubin, w, M)
Dielectric behavior of water-bearing sediments (W. O. Smith, w, W)
Ground-water mechanics, treatise (J. G. Ferris, w, Tucson, Ariz.)
Laboratory hydraulic experiments with porous earth material (H. E. Skibitzke, w, Phoenix, Ariz.)
Mechanics of aquifers—principles of compaction and deformation (J. F. Poland, w, Sacramento, Calif.)
Mechanics of fluid flow in porous media (A. Ogata, h, Honolulu, Hawaii)
Mechanics of ground-water flow (H. H. Cooper, Jr., w, W)
Permeability distribution study—Atlantic Coastal Plain (P. M. Brown, w, Raleigh, N.C.)
Permeability of fractured rocks (F. W. Trainer, w, W)
Regional hydrologic system analysis—hydrodynamics (R. R. Bennett, w, W)
Regional hydrologic system analysis—permeability distribution (J. D. Bredehoeft, w, W)
Research on laboratory and field methods (A. I. Johnson, w, D)
Theory of multiphase flow—applications (R. W. Stallman, w, D)
Transient flow in sediments (W. O. Smith, w, W)
Unsaturated flow of water in sediments (W. O. Smith, w, W)
California:
Aquifer-test reevaluation (E. J. McClelland, w, Sacramento)
Permeability research (A. I. Johnson, w, D)
Specific-yield research (A. I. Johnson, w, D)
Kansas, gravity flow of water in soils and aquifers, western part of State (R. C. Prill, g, Lawrence)
New Mexico, fluid dynamics of the Bandelier Tuff (J. L. Kunkler, g, Albuquerque)
Hydraulics, surface flow:
Channel characteristics:
Large-scale roughness (J. Davidian, w, W)
Manning coefficient, determination from measured bed roughness in natural channels (J. T. Limerinas, w, M)
Sand-channel streams, controls (F. A. Kilpatrick, w, Fort Collins, Colo.)
Vegetation and alluvial processes in a semiarid environment (R. G. Zimmerman, w, Baltimore, Md.)
Channel constrictions:
Bridge-site investigations, Glacier Creek, Chulitna, and Tok Rivers, Alaska (V. K. Berwick, w, Juneau)
Bridge-site verifications, Louisiana (J. D. Camp, w, Baton Rouge)

Hydraulics, surface flow--Continued
Hydraulic factors, field measurement:
Ice formation and ablation—effects on open-channel flow (K. L. Carey, s, Madison, Wis.)
Performance of channel changes (P. O. Jefferson, w, Tuscaloosa, Ala.)
Performance of culverts (P. O. Jefferson, w, Tuscaloosa, Ala.)
Overall efficiency of bridges (K. V. Wilson, w, Jackson, Miss.)
Scour research at bridge piers on Knik and Susitna Rivers, Alaska (L. S. Leveen, w, Anchorage)
Verification of hydraulic computation methods for bridge sites (C. O. Ming, w, Tuscaloosa, Ala.)
Verification of hydraulic techniques (W. J. Randolph, w, Nashville, Tenn.)
Flow characteristics:
Cross-channel diffusion (R. R. Wright, w, Atlanta, Ga.)
Dispersion by turbulent flow in open channels (N. Yotsukura, w, W)
Longitudinal dispersion in flow in irregular open channels (H. B. Fischer, w, California Inst. Technology, Pasadena)
Mechanics of flow structure and fluid resistance—movable boundary (E. V. Richardson, w, Fort Collins, Colo.)
Mechanics of fluid resistance (H. J. Tracy, w, Atlanta, Ga.)
Unsteady flow in natural channels (R. A. Baltzer, w, W)
Vertical-velocity characteristics, Columbia River gaging stations, Washington and Oregon (J. Savini, G. L. Bodhaine, w, Tacoma, Wash.)
Laboratory studies:
Grain-size distribution and bedload transport (G. Williams, L. B. Leopold, w, W)
Laboratory studies of open-channel flow (H. J. Tracy, w, Atlanta, Ga.)
Systems analysis of hydrologic processes (G. F. Smoot, w, W)
Time-of-travel studies:
Solutes (J. F. Wilson, Jr., w, W)
Indiana (R. E. Hoggatt, w, Indianapolis)
New Jersey (T. J. Buchanan, s, Trenton)
New York (B. Dunn, w, Albany)
North Carolina, stream-channel characteristics and time-of-travel studies (N. O. Thomas, H. G. Hinson, w, Raleigh)
Ohio, Great Miami River (H. P. Brooks, w, Columbus)
Oregon, Willamette River basin (D. D. Harris, s, Portland)
See also Hydrologic instrumentation.
Hydrologic-data collection and processing:
Automation systems and equipment for water (W. L. Isherwood, w, W)
Data-collection program, new criteria (M. A. Benson, w, W)
Data-processing methods, evaluation (A. L. Johnson, g, D)
Data storage, retrieval, and application by digital-computer techniques (C. O. Morgan, g, Lawrence, Kans.)
Digital-computer method for computing sediment discharge (M. D. Edwards, w, Arlington, Va.)
Drainage-area determinations:
Arkansas (R. C. Christensen, w, Little Rock)
Indiana (R. E. Hoggatt, w, Indianapolis)

230-568 O-67—17

Water resources--Continued
- Northeastern States, effect of drought on water resources (D. O'Bryan, W. J. Schneider, H. C. Barksdale, w, W)
- Ohio River basin (M. Deutsch, w, Gahanna, Ohio)
- Public domain:
  - Pacific coast area, water-supply exploration (C. T. Snyder, w, M)
  - Rocky Mountain area, water-supply exploration (M. C. Van Lewen, 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.)
- Upper Mississippi River basin (P. R. Jordan, w, Gahanna, Ohio)
- Electrical analog models:
  - Georgia, Florida, South Carolina, and Alabama, principal artesian aquifer, Ocala Limestone (R. L. Wait, w, Brunswick, Ga.)
  - Texas, Louisiana, aquifers in Gulf coast area (A. N. Turcan, Jr., w, Baton Rouge, La.)
  - Texas, New Mexico, Ogallala Formation, Southern High Plains (J. G. Cronin, w, Austin, Tex.; J. S. Havens, w, Carlsbad, N. Mex.)
- Alabama (w, Tuscaloosa):
  - Hydrogeologic study of State (W. J. Powell)
  - Hydrologic atlas of State (C. F. Hains)
  - Relation of oil and gas industry to water resources (W. J. Powell)
  - Ground water:
    - Cullman County (R. J. Faust)
    - Greene County (K. D. Wahl)
    - Hale County (T. H. Sanford)
    - Marion County (L. V. Causey)
    - Sumter County (T. H. Sanford)
  - Water resources:
    - Southwest part (J. R. Avrett)
    - Choctawhatchee-Escambia River basins (J. C. Scott)
    - Coosa River basin, upper part (J. R. Harkins)
    - Tombigbee-Black Warrior River basin, upper part (K. D. Wahl)
- Alaska (w, Anchorage):
  - Ground water:
    - Douglas area (W. W. Barnwell)
    - Haines-Port Chilkoot area (A. J. Feulner)
    - National Parks (D. A. Morris)
    - Skagway area (A. J. Feulner)
    - Statewide inventory (P. J. Still)
    - U. S. Customs Station, Alaska-Canada boundary, water supply (A. J. Feulner)
  - Hydrology:
    - Anchorage area (D. A. Morris)
    - Tanana basin (G. S. Anderson)
  - Surface water:
    - Bank erosion, Knik estuary (S. H. Jones)
    - Dye-dilution study (R. S. George)
    - Small-streams program (S. H. Jones)
  - Water resources:
    - Mendenhall Valley, development of water supplies (W. W. Barnwell, C. W. Boning)
    - U. S. Air Force stations (A. J. Feulner)
- American Samoa (w, Honolulu, Hawaii):
  - Ground water (K. J. Takasaki)
  - Surface water (S. Valenciano)

Water resources--Continued
- Arizona (w, Tucson):
  - East Verde River, transmountain diversion studies (E. S. Davidson)
  - Ground water:
    - Analysis of water-level declines (E. B. Hodges)
    - Beardsley area (W. Kam)
    - Big Sandy Valley (W. Kam)
    - Coconino County, southern part (E. H. McGavock)
    - Kingman area (J. B. Gillespie)
    - Navajo Indian Reservation (M. E. Cooley)
    - Safford area (E. S. Davidson)
    - Tucson basin (E. S. Davidson)
    - Tucson basin, northern part (E. F. Pashley, Jr.)
    - Willcox basin (S. G. Brown)
    - Williams, analysis of public water supply (B. W. Thomsen)
  - Hydrology, alluvial basins (M. E. Cooley)
  - Water resources, Sycamore Creek basin (B. W. Thomsen)
- Arkansas (w, Little Rock):
  - Ground water:
    - Arkansas River valley (M. S. Bedinger)
    - Lower Red River valley (A. H. Ludwig)
  - Water resources:
    - Clark, Cleveland, and Dallas Counties (R. O. Plebuch)
    - Clay, Craighead, Greene, and Poinsett Counties (M. S. Hines)
    - Grant and Hot Spring Counties (H. N. Halberg)
    - Lawrence and Randolph Counties (A. G. Lamonds)
    - White River basin (G. M. Hogensen)
- California (w, Menlo Park):
  - Ground water:
    - Antelope Valley:
      - East Kern Water Agency (R. M. Bloyd, Jr.)
      - Eastern part (J. H. Koehler)
    - Barstow, Marine Corps Supply Center (G. A. Miller)
    - Borrego Valley (W. R. Moyle, Jr.)
    - Bristol, Broadwell, Cadiz, Danby, and Lavic Valleys (W. R. Moyle, Jr.)
    - Camp Pendleton Marine Corps Base (F. W. Giessner)
    - Central Valley, ground-water withdrawals (W. Ogilbee)
    - China Lake, Naval Ordnance Test Station (J. A. Westphal)
    - Cronise, Silver, and Soda Valleys (W. R. Moyle, Jr.)
    - Cuyama Valley (W. V. Swarzenski)
    - Death Valley National Monument (G. A. Miller)
    - Edwards Air Force Base (F. W. Giessner)
    - Elwood-Gaviota area (W. V. Swarzenski)
    - Fresno area (R. W. Page)
    - Hanford-Visalia area (M. G. Croft)
    - Indian Wells Valley, appraisal (W. R. Moyle, Jr.)
    - Madera area (H. T. Mitten)
    - Orange County, analog model (E. H. Cordes)
    - Panamint and Searles Valleys (W. R. Moyle, Jr.)
    - Pinnacles National Monument (J. P. Akers)
    - San Joaquin Valley, southern part (M. G. Croft)
    - San Luis Rey River valley area (J. H. Koehler)
    - Santa Ana area, upper part, south coastal area (J. J. French)

Water resources--Continued
- Kansas (g, Topeka):
  - Analysis of hydrologic data (J. M. McNellis)
  - Electrical analog model studies of areal hydrologic problems (J. D. Winslow, g)
  - Ground water:
    - Northwestern part (E. D. Jenkins)
    - Southwestern part (W. R. Meyer)
    - Allen County (D. E. Miller)
    - Butler County (C. O. Morgan)
    - Cherokee County (W. J. Seevers)
    - Decatur County (W. G. Hodson)
    - Ellsworth County (C. K. Bayne)
    - Finney County (W. R. Meyer)
    - Hamilton County (W. R. Meyer)
    - Jefferson County (J. D. Winslow)
    - Johnson County (H. G. O'Connor)
    - Kearny County (W. R. Meyer)
    - Labette County (W. L. Jungmann)
    - Montgomery County (H. G. O'Connor)
    - Pratt County (D. W. Layton)
    - Republican River valley (S. W. Fader)
    - Rush County (J. McNellis)
  - Water resources:
    - Kansas Valley — Abilene to Kansas City (S. W. Fader)
    - Nemaha County (C. K. Bayne)
    - Washington County (D. E. Miller)
- Kentucky (g, Louisville):
  - Ground water, Jackson Purchase area (R. W. Davis)
  - Water resources:
    - Bell County, upper Yellow Creek basin (D. S. Mull)
    - Mammoth Cave area (R. V. Cushman)
    - Tradewater River basin (H. F. Grubb)
- Louisiana (w, Baton Rouge):
  - Ground water:
    - Avoyelles Parish (J. R. Marie)
    - Lower Red River valley (M. S. Bedinger, w, Little Rock, Ark.)
    - Norco area (P. B. Bieber)
  - Surface water, gazetteer of streams (V. B. Sauer)
  - Water resources:
    - Southwestern part (A. H. Harder, S. M. Rogers)
    - Little River basin (M. W. Gaydos)
    - Ouachita Parish (J. E. Rogers)
    - Plaquemine–White Castle area (C. D. Whiteman, Jr.)
    - Pointe Coupee Parish (M. D. Winner, Jr.)
- Maine, ground water, Lower Androscoggin basin (G. C. Prescott, g, Augusta)
- Maryland:
  - Effect of drought on water resources, Regional Study 1 (D. O'Bryan, w, W)
  - Ground water:
    - Baltimore County, use of ground water (C. P. Laughlin, w, College Park)
    - Susquehanna River basin (P. R. Seaber, g, Harrisburg, Pa.)
  - Water resources:
    - Dorchester and Talbot Counties (F. K. Mack, w, Annapolis)
    - Georges Creek basin, a corner of Appalachia (D. O'Bryan, J. W. Crooks, w, W)

Water resources--Continued
- Maryland--Continued
  - Water resources--Continued
    - Lower Bay Counties (Calvert, Charles, and St. Marys) (E. G. Otton, w, Towson)
    - Patuxent River basin (J. W. Crooks, D. O'Bryan, w, W)
    - Salisbury area (D. H. Boggess, w, Salisbury)
- Massachusetts (w, Boston):
  - Ground water:
    - Assabet River basin (S. J. Pollock)
    - Boston, central area (J. E. Cotton)
    - Cape Cod National Seashore (R. G. Petersen)
    - Lower Merrimack valley (J. E. Cotton)
    - Ten Mile–North Taunton Rivers basin (J. R. Williams)
  - Water resources:
    - Connecticut River basin (D. J. Cederstrom)
    - Housatonic River basin (R. F. Norvitch)
    - Millers River basin (M. R. Collings)
- Michigan (w, Lansing):
  - Hydrology of river-based recreation (G. E. Hendrickson)
  - Ground water:
    - Iron County (G. E. Hendrickson)
    - Oakland County (F. R. Twenter)
    - Tri-County area (K. E. Vanlier)
  - Surface water, Manistee and Pere Marquette Rivers (G. E. Hendrickson)
  - Water resources:
    - Branch County (L. E. Stoimenoff)
    - Grand River basin (K. E. Vanlier)
    - Kalamazoo County (J. B. Miller)
- Minnesota (g, St. Paul):
  - Ground water:
    - Hibbing area (G. F. Lindholm)
    - St. James area (L. H. Ropes)
  - Hydrogeology, Twin Cities metropolitan area (H. O. Reeder)
  - Hydrologic parameters controlling recreational use of Minnesota rivers (R. F. Brown)
  - Water-resources reconnaissance of watershed units:
    - Buffalo River unit (R. W. Maclay)
    - Chippewa River unit (R. D. Cotter)
    - Cottonwood River (W. A. Van Voast)
    - Crow Wing River drainage basin (E. L. Oakes)
    - Kettle River unit (E. L. Oakes)
    - Lac qui Parle River unit (R. D. Cotter)
    - Mississippi Headwaters unit (E. L. Oakes)
    - Mustinka–Bois de Sioux units (R. W. Maclay)
    - Otter Tail River unit (T. C. Winter)
    - Pomme de Terre River unit (R. D. Cotter)
    - Red Lake River (R. W. Maclay)
    - Redwood River (W. A. Van Voast)
    - Roseau River unit (T. C. Winter)
    - Snake River (E. L. Oakes)
    - Two Rivers unit (R. W. Maclay)
    - Wild Rice River (R. W. Maclay)
    - Yellow Medicine River (W. A. Van Voast)
- Mississippi (w, Jackson):
  - Geology and ground water:
    - Big Black River basin (B. E. Wasson)
    - Pearl River basin (J. W. Lang)

Water resources--Continued
North Carolina--Continued
Surface water:
Interpretation of surface-water data (G. C. Goddard)
Neuse River headwaters, surface-water resources (J. F. Turner, Jr.)
North Dakota (g, Bismarck):
Ground water:
Burke and Mountrail Counties (J. L. Hatchett)
Cass County (R. L. Klausing)
Divide County (C. A. Armstrong)
Eddy and Foster Counties (H. Trapp)
Grand Forks County (T. E. Kelly)
Renville and Ward Counties (W. A. Pettyjohn)
Richland County (C. H. Baker, Jr.)
Traill County (H. Jensen)
Wells County (F. J. Buturla, Jr.)
Williams County (E. A. Ackroyd)
Ohio (w, Columbus):
Ground water:
Northeastern part, principal aquifers (J. L. Rau)
Lower Great Miami River basin (A. M. Spieker)
Mill Creek valley, analog model study (R. E. Fidler)
Piketon, aquifer test (S. E. Norris, R. E. Fidler)
Oklahoma (g, Oklahoma City):
Fort Smith quadrangle, central-eastern Oklahoma (M. V. Marcher)
Special investigations and reports (J. H. Irwin)
Ground water:
Arkansas River valley, eastern part of State (M. S. Bedinger, w, Little Rock, Ark.)
Arkansas and Verdigris River valleys (H. H. Tanaka)
Lower Red River valley (M. S. Bedinger, w, Little Rock, Ark.)
Texas County (P. R. Wood)
Oregon (w, Portland):
Ground water:
Eola-Amity Hills area (D. Price)
French Prairie area (D. Price)
Molalla-Salem slope area (E. R. Hampton)
North Santiam River basin (D. Helm)
Water resources, Willamette Basin, availability and appraisal of water resources (A. R. Leonard)
Pennsylvania (g, q, s, Harrisburg):
Gazetteer of Pennsylvania streams (W. F. Busch, s)
Ground water:
Chester County, metamorphic and igneous rocks (C. W. Poth, g)
Lancaster County, carbonate rocks (H. Meisler, g)
Loysville quadrangle (H. E. Johnston, g)
Luzerne County, Wyoming Valley (J. R. Hollowell, g)
Martinsburg Shale, Lehigh and Northhampton Counties (C. W. Poth, g)
Mifflintown quadrangle (H. E. Johnston, g)
Susquehanna River basin (P. R. Seaber, g)
Water resources, Schuylkill River basin (J. E. Biesecker, q)
Puerto Rico (w, San Juan):
Water resources:
Guánica area (N. E. McClymonds)
Guayanilla-Yauco area (J. W. Crooks, I. G. Grossman, D. B. Bogart)
Jobos area (N. E. McClymonds)

Water resources--Continued
Puerto Rico--Continued
Water resources--Continued
Juana Díaz area (E. V. Giusti)
Ponce area (N. E. McClymonds)
Tallaboa Valley (I. G. Grossman, J. W. Crooks, D. B. Bogart)
Rhode Island (w, Boston, Mass.)
Ground water:
Potowomut-Wickford area (J. S. Rosenshein)
South Branch Pawtuxet River basin (J. B. Gonthier)
Water resources, Lower Pawcatuck River basin (J. S. Rosenshein)
South Carolina (w, Columbia):
Ground water:
Coastal plain:
Northeastern part, geology and ground-water resources (G. E. Siple)
Subsurface geology and hydrology (G. E. Siple)
Leesville area, potential sand aquifers (G. E. Siple, W. D. Paradeses)
Piedmont, alluvial aquifers (G. E. Siple)
Savannah River Plant, operational effect on geologic and hydrologic environment (G. E. Siple)
South Dakota (g, Huron):
Ground water:
Eastern part, hydrology of glacial drift in selected drainage basins: Big Sioux Basin from Sioux Falls to Brookings County line (M. J. Ellis)
Studies of artesian wells and selected shallow aquifers (D. G. Adolphson)
Bon Homme County (D. G. Jorgensen)
Campbell County (N. C. Koch)
Clay County (J. C. Stephens)
Dakota Sandstone (E. F. LeRoux)
Pine Ridge Indian Reservation (M. J. Ellis)
Rosebud Indian Reservation (M. J. Ellis)
Tennessee (w, Nashville):
Water resources:
Memphis area (E. A. Bell)
Stones River basin, upper (G. K. Moore)
Trace Creek (J. H. Criner, Jr.)
Texas (w, Austin):
Ground water:
Alibates Flint Quarries and Texas Panhandle Culture National Monument, occurrence and availability of ground water (B. N. Myers)
Atascosa County (W. H. Alexander, Jr.)
Austin County (C. L. Wilson)
Bastrop County (C. R. Follett)
Bee County (B. N. Myers)
Brazos River alluvium, occurrence and availability of ground water (J. G. Cronin)
Brooks County (B. N. Myers)
Chambers County (J. B. Wesselman)
Ellis County (G. L. Thompson)
El Paso area, continuing quantitative studies (M. E. Davis)
Frio County (W. H. Alexander, Jr.)
Galveston County (R. K. Gabrysch)
Guadalupe County (G. H. Shafer)
Harrison County (M. E. Broom)
Houston district, continuing quantitative studies (R. K. Gabrysch)
Jasper County (J. B. Wesselman)
Jefferson County (J. B. Wesselman)
Johnson County (G. L. Thompson)

- **Water resources**--Continued
  - Texas--Continued
    - Ground water--Continued
      - Kendall County (R. D. Reeves)
      - Kerr County (R. D. Reeves)
      - Kimble County (J. H. Patman)
      - Lee County (G. L. Thompson)
      - Liberty County (R. B. Anders)
      - Lower Red River valley (A. H. Ludwig, w, Little Rock, Ark.)
      - Maverick County (W. H. Alexander, Jr.)
      - Montgomery County (B. P. Popkin)
      - Newton County (J. B. Wesselman)
      - Nueces County (G. H. Shafer)
      - Polk County (G. H. Tarver)
      - Sabine County (R. B. Anders)
      - San Antonio area (S. Garza)
      - San Augustine (R. B. Anders)
      - San Jacinto County (W. M. Sandeen)
      - San Patricio County (G. H. Shafer)
      - Tyler County (G. R. Tarver)
      - Upton County (D. E. White)
      - Waller County (C. L. Wilson)
      - Webb County (W. H. Alexander, Jr.)
      - Wood County (M. E. Broom)
    - Hydrologic investigations:
      - Brazos River, tidal flow (R. E. Smith)
      - Calaveras Creek, small-watershed hydrology (J. T. Smith)
      - Cow Bayou, small-watershed hydrology (W. B. Mills)
      - Escondido Creek, small-watershed hydrology (F. W. Kennon)
      - Little Elm Creek, small-watershed hydrology (E. E. Schroeder)
      - Pin Oak Creek, small-watershed hydrology (J. T. Smith)
  - Utah (w, Salt Lake City):
    - Ground water:
      - Statewide ground-water conditions (J. Hood)
      - Cedar Valley (R. D. Feltis)
      - Juab Valley, northern part (L. J. Bjorklund)
      - Sanpete Valley (G. B. Robinson, Jr.)
      - Skull Valley, hydrologic reconnaissance (J. Hood)
      - Utah Valley, southern part (R. M. Cordova)
    - Water resources, Salt Lake County (A. G. Hely)
  - Vermont (w, Boston, Mass.)
    - Ground water, statewide reconnaissance (A. L. Hodges)
  - Virgin Islands (w, San Juan, Puerto Rico):
    - St. Croix (D. G. Jordan, O. J. Cosner)
    - St. John (O. J. Cosner)
    - St. Thomas (D. G. Jordan, O. J. Cosner)
    - Virgin Islands National Park (O. J. Cosner)
  - Washington (w, Tacoma):
    - Lower Flett Creek basin, hydrology (F. M. Veatch)
    - Ground water:
      - Adams County, eastern (J. W. Bingham)
      - Adams, Franklin, and Grant Counties (J. W. Bingham)
      - Island County (H. W. Anderson, Jr.)
      - King County, southwest (J. E. Luzier)
      - Klickitat County, central (J. E. Luzier)
      - Mason County (D. Molenaar)
      - Odessa area, optimum ground-water withdrawal rate (A. A. Garrett)
      - Olympic National Park (K. L. Walters)
      - Spokane County, northern (D. R. Cline)

- **Water resources**--Continued
  - Washington--Continued
    - Ground water--Continued
      - Whitman County (K. L. Walters)
    - Water resources:
      - Colville River basin (W. R. Scott)
      - Coulee Dam National Recreation Area (H. W. Anderson)
      - King County (D. Richardson)
  - West Virginia (w, Charleston):
    - Little Kanawha River basin (P. E. Ward)
    - Monongahela River basin (P. E. Ward)
  - Wisconsin (g, Madison):
    - Ground water, Kenosha and Racine Counties (R. D. Hutchinson)
    - Water resources:
      - Central Wisconsin River valley (R. W. Devaul)
      - Fox-Wolf River basin (P. G. Olcott)
      - Fox (Illinois) River basin (R. D. Hutchinson)
      - Walworth County (J. H. Green)
  - Wyoming (g, s, Cheyenne)
    - East Fork area near Boulder, hydrology (D. J. O'Connell, s, Riverton)
    - Ground water:
      - Cheyenne area (L. J. McGreevy, g)
      - Green River structural basin, reconnaissance (G. E. Welder, g)
      - Wind River basin, reconnaissance (H. A. Whitcomb, g)
      - Wind River Indian Reservation (L. J. McGreevy, g)
  - Other countries:
    - Afghanistan, surface water, national program (A. O. Westfall, w, Kabul)
    - Brazil:
      - Hydrogeology, northeastern part (S. L. Schoff, w, Recife)
      - Surface water:
        - Northeastern part (R. O. R. Martin, w, Recife)
        - National program (F. F. LeFever, w, Rio de Janeiro)
    - Korea, ground-water investigation in Han River basin (J. T. Callahan, w, Seoul)
    - Nepal, surface water, nationwide investigations (W. W. Evett, w, Katmandu)
    - Nigeria:
      - Ground water, national program (D. A. Phoenix, w, Kaduna)
      - Hydrogeology:
        - Chad Basin (G. C. Tibbitts, Jr., w, Maiduguri)
        - Sokoto Basin (H. R. Anderson, w, Sokoto)
      - Surface water:
        - Eastern part (E. Lucero, w, Enugu)
        - Northern part (C. R. Seiber, w, Kaduna)
    - Okinawa:
      - Ground water, southern part (D. A. Davis, Honolulu)
      - Sedimentation investigation, northern part (J. P. Beverage, w, M)
    - Pakistan, hydrologic investigations related to waterlogging and salinity control in the Punjab Reion (M. J. Mundorff, w, Lahore)
    - United Arab Republic (Egypt), ground-water investigation and pilot development in the New Valley project (R. L. Cushman, w, Cairo)
- **Zeolites:**
  - Southeastern California (R. A. Sheppard, D)
- **Zinc.** See Lead and Zinc.

CONTENTS OF GEOLOGICAL SURVEY RESEARCH 1966, CHAPTERS B, C, AND D

Listed below are the contents of Professional Papers 550–B, –C, and –D, comprising 130 papers, many of which are cited in the preceding pages. References to the papers are given in the text in the following form: Blacet (p. B1–B5); the chapter is identified by the letter preceding the page number.

CHAPTER B

GEOLOGIC STUDIES

Geochemistry

Geochronology

Volcanology

Economic geology

Analytical techniques and instrumentation

HYDROLOGIC STUDIES

Surface water

Experimental hydrology

TOPOGRAPHIC MAPPING

Mapping equipment

CHAPTER C

GEOLOGIC STUDIES

230-568 O-67—18

CHAPTER D

GEOLOGIC STUDIES

Geochemistry

Geochronology

Economic geology

Analytical methods

HYDROLOGIC STUDIES

Ground water

Quality of water

Limnology

Radiohydrology

Test-well construction

Analysis of water

PUBLICATIONS IN FISCAL YEAR 1966

A complete list of abstracts, papers, reports, and maps (exclusive of topographic maps) by U.S. Geological Survey authors and published or otherwise released to the public during fiscal year 1966 (July 1, 1965–June 30, 1966) is given below. Publications are listed alphabetically by senior author. Because many Geological Survey authors collaborate with colleagues from outside the Survey in the preparation of reports published both by the Survey and by cooperating agencies and of articles in technical journals, not all the senior authors of the publications listed below are members of the U.S. Geological Survey.

Each citation is identified by an acquisition number that was used in computer compilation of the list (the numbers are prefixed by "r" in the text to avoid confusion with dates). References to this list are identified in the preceding text by author and acquisition number: for example, J. W. Adams (r1276).

The list also includes a number of publications that were not listed in "Geological Survey Research 1965" and earlier volumes.

Ables, Paula G. *See* M'Gonigle, John W. 0988

1276 **Adams, J. W.** Rare earths, *in* Mineral and water resources of New Mexico: U.S. Cong., 89th, 1st sess., Senate Comm. Interior and Insular Affairs, Comm. Print (New Mexico Bur. Mines and Mineral Resources Bull. 87), p. 234–237, 1965.

Adams, John W. *See* Staatz, Mortimer H. 1759

1293 **Addicott, W. O.** On the identification of *Schizopyga californiana* Conrad, a California Pliocene gastropod: California Acad. Sci. Proc., 4th ser., v. 33, no. 2, p. 47–58, illus., table, 1965.

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Wilshire, Howard G. *See* Seeland, David A. 1751

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Zandle, G. L. *See* Boynton, G. R. 0287

Zandle, G. L. *See* Boynton, G. R. 0288

Zaudle, G. L. *See* Boynton, G. R. 0443

Zaudle, G. L. *See* Boynton, G. R. 0444

Zaudle, G. L. *See* Boynton, G. R. 0445

Zandle, G. L. *See* Boynton, G. R. 0446

Zandle, G. L. *See* Boynton, G. R. 0480

Zandle, G. L. *See* Boynton, G. R. 1309

Zaudle, G. L. *See* Boynton, G. R. 1310

Zaudle, G. L. *See* Boynton, G. R. 1311

Zandle, G. L. *See* Boynton, G. R. 1312

Zaudle, G. L. *See* Boynton, G. R. 1313

Zandle, G. L. *See* Boynton, G. R. 1314

Zandle, G. L. *See* Boynton, G. R. 1477

Zandle, G. L. *See* Boynton, G. R. 1478

Zaudle, G. L. *See* Boynton, G. R. 1479

Zandle, G. L. *See* Boynton, G. R. 1480

Zandle, G. L. *See* Boynton, G. R. 1481

Zaudle, G. L. *See* Boynton, G. R. 2001

Zandle, G. L. *See* Boynton, G. R. 2002

Zaadle, G. L. *See* Boynton, G. R. 2003

Zaadle, G. L. *See* Boynton, G. R. 2004

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Zenger, Donald H. *See* Berdan, Jean M. 1250

Zietz, Isidore. *See* Pakiser, L. C. 1912

PUBLICATIONS INDEX

[Numbers refer to entries in list "Publications in Fiscal Year 1966"]

SUBJECT INDEX

[Some discussions cover more than one page, but only the number of the first page is given. See also Investigations in Progress (p. 223) and Publications Index (p. 321)]

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

T

See also Investigations in Progress and Publications Index

See also Investigations in Progress and Publications Index

INVESTIGATOR INDEX

[See also Publications in Fiscal Year 1966 (p. 265)]

[See also Publications in Fiscal Year 1966]

[See also Publications in Fiscal Year 1966]

[See also Publications in Fiscal Year 1966]

[See also Publications in Fiscal Year 1966]

[See also Publications in Fiscal Year 1966]

[See also Publications in Fiscal Year 1966]

U.S. GOVERNMENT PRINTING OFFICE : 1967 O—230-568