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March 3, 1849

GEOLOGICAL SURVEY RESEARCH 1967

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 575–A

GEOLOGICAL SURVEY RESEARCH 1967

GEOLOGICAL SURVEY PROFESSIONAL PAPER 575

Significant results of investigations for fiscal year 1967, 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: 1967

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

GEOLOGICAL SURVEY
William T. Pecora, Director

GEOLOGICAL SURVEY RESEARCH 1967

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 575–A

A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal year 1967, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1967

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FOREWORD

"Geological Survey Research 1967" is the eighth 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 575. 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 1967," beginning on page A269. The tables of contents for chapters B through D are listed on pages A263–A268.

Numerous Federal, State, county, and municipal agencies and other organizations and counties listed on pages A217–A221 made significant financial contributions 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 1967." Reference is made to only a few. Louis Pavlides, Geologic Division, was responsible for organizing and assembling chapter A and for critical review of papers in chapters B–D, assisted by Edward Bradley, Water Resources Division. Marston S. Chase and Jesse R. Upperco, Publications Division, were in charge of production aspects of the series, assisted by Humbert S. Revel in technical editing, and William H. Elliott and James R. Hamilton in planning and preparing illustrations.

The volume for next year, "Geological Survey Research 1968," will be published as chapters of Professional Paper 600. 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
Geological Survey Research 1966—Prof. Paper 550

William T. Pecora

WILLIAM T. PECORA,
Director.

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REFERENCES

Text references are in three forms:

H. R. Cornwall and others (p. B10–B20)

Refers to a short paper published in a chapter of "Geological Survey Research 1967." The letter preceding the page numbers identifies the chapter. The tables of contents for the short-paper chapters are on p. A263–A268.

S. H. Patterson (r1006)

Refers to a publication released in fiscal year 1967 and at least one of whose authors is a member of the U.S. Geological Survey. The number is the acquisition number used in computer compilation of the list of publications that begins on p. A269. (In the text, the prefix "r" replaces the first cipher of the acquisition number.)

Footnotes

Used for those publications that were released before fiscal year 1967, that are in press, or whose authors are not members of the U.S. Geological Survey.

ABBREVIATIONS

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

A	angstrom units
a-c	alternating current
amp	amperes
bbl	barrels
bgd	billion gallons per day
B.P.	Before Present
Btu	British thermal units
cal	calories
cal per sec	calories per second
cfs	cubic feet per second
cfs per sq mi	cubic feet per second per square mile
cm	centimeters
cu cm	cubic centimeters
cu ft	cubic feet
cu km	cubic kilometers
cu m	cubic meters
°C per km	degrees C per kilometer
d-c	direct current
fpm	feet per minute
fps	feet per second
ft	feet
g	grams
g per cu cm	grams per cubic centimeter
g per day per sq m	grams per day per square meter
gpd	gallons per day
gpd per ft	gallons per day per foot
gph	gallons per hour
gpm	gallons per minute
gpm per ft	gallons per minute per foot
hp	horsepower
hr	hour
kb	kilobars
kcal	kilocalories
kcal per sec	kilocalories per second
km	kilometers
km per sec	kilometers per second
l	liters
lb	pounds
lb per cu ft	pounds per cubic foot
m	meters
mg	milligrams
mg per l	milligrams per liter
mgal	milligals
mgd	million gallons per day
ml	milliliters
mm	millimeters
mp	melting point
mph	miles per hour
mv	millivolts
mμ	millimicrons
m.y.	million years
μ	microns
μg	micrograms
μg per l	micrograms per liter
μl	microliters
μmhos	micromhos
oz	ounces
oz per ton	ounces per ton
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
psf	pounds per square foot
psi	pounds per square inch
sec	seconds
sq ft	square feet
sq ft per sec	square feet per second
sq km	square kilometers
sq m	square meters
sq mi	square miles
sq mi per day	square miles per day
tons per sq mi	tons per square mile
tons per sq mi per yr	tons per square mile per year
T.U.	tritium units
w	watts

GEOLOGICAL SURVEY RESEARCH 1967

INVESTIGATIONS OF NATURAL RESOURCES

The Act of Congress that created the U.S. Geological Survey in 1879 charged its Director with "the classification of the public lands," and with the "examination of the geological structure, mineral resources and products of the national domain". These responsibilities and objectives remain as its central guidelines.

To help meet the ever-pressing needs of maintaining an adequate mineral-, fuel-, and water-resource base for the Nation, the Survey is carrying out a continuing program of investigations that includes both classical as well as sophisticated modern techniques of earth-science studies. These investigations range from direct applied research to pure research; the highlights of the investigations during fiscal year 1967 are summarized in this volume.

MINERAL RESOURCES

The demands of an increasing population and a continually improving standard of living require an ever-increasing supply of minerals and mineral fuels. If our Nation is to maintain or improve the present standard of living we now enjoy, the ability to find and efficiently utilize mineral resources must be accelerated to keep pace with the increasing needs. It has been estimated that our mineral consumption will nearly double by 1980 and that our energy needs, most of which must be met by mineral fuels, will double by 1990. One of the principal missions of the Geological Survey is to aid in assuring that the United States maintains a sufficient mineral-resource base to sustain these anticipated needs.

The Survey activities that bear most directly on mineral resources include location of target areas for exploration; assessment of mineral resources of individual commodities, and of regions or States; and development of geochemical and geophysical instruments and techniques for locating mineral deposits. The Survey also, through its Office of Mineral Exploration, assists private industry financially in the exploration for certain mineral commodities.

Geologic, geochemical, and geophysical investigations during the last year resulted in the location of a number of new targets and potential sources for heavy metals, base and ferrous metals, light metals, industrial minerals, radioactive materials, and organic fuels. This was the first full year of the new heavy-metals program, an intensified effort to increase the resource base of gold, silver, platinum, mercury, and certain other heavy metals in short domestic supply. Although this program has been in existence only a short time, several areas of potential heavy-metals resources have been located and new techniques of detecting these metals have been developed. Some of the more important results of this work are the discovery of gold and other heavy metals at Cortez and Goldfield, Nev., and at Cripple Creek, Colo.; the construction and development of two prototype neutron-activation instruments for in-situ detection of silver; and the development of new sensitive procedures for detecting platinum, palladium, gold, and bismuth. Also, a description of a simple mercury detector was published. Some advances in other commodities in fiscal year 1967 are the discovery of anomalously high concentrations of rhenium in some molybdenum ores, recognition that the deposits of dawsonite in the Piceance basin of Colorado may be an enormously large new source of aluminum, report of a new occurrence of humate in northwest Florida, geologic mapping of about 2½ billion tons of coal in southern Utah, and location of several targets for uranium ore.

Mineral-resource appraisals of many areas and assessments of United States and world reserves of several mineral commodities were made during the past year. The Wilderness Act of 1964 and accompanying Conference Report directed the Geological Survey and Bureau of Mines to make mineral surveys of lands which are being considered for inclusion in the National Wilderness Preservation System. Mineral surveys have been completed or are in progress in 19 primitive areas being considered for inclusion in the Wilderness System; reports on 12 of these areas have been published as Geological Survey Bulletins, 7 of which were published during the past year and are briefly described in this report. In addition, mineral-appraisal reports on 33 Wildlife Refuges were prepared and placed on open file for public inspection. Reports on the mineral resources of the Appalachian region and of Missouri were completed and are now in press. Reports on estimates of the energy resources of the United States and the world and the bauxite resources of the world also were published during the year.

RESOURCE COMPILATION

MINERAL RESOURCES OF MISSOURI

The mineral resources of Missouri have been summarized in a report [1, 2] prepared in collaboration with the Missouri Division of Geological Survey and Water Resources and other Federal agencies. The distribution of all mineral resources in Missouri is described, together with data on mineral production and use. Missouri's mineral industry began about 1700 with the discovery of lead deposits by early French explorers; lead mining has been nearly continuous since early in the 19th century. Recent discovery of major new deposits in southeast Missouri has led to considerable expansion in mine development and production capacity. These new facilities not only promise to maintain Missouri's position as the leading State in producton of lead, but also may reverse a 20-year national trend toward greater dependence on foreign sources of lead, and once again establish this country as a net exporter. New deposits of iron ore also have been placed in production, exploiting deeply buried deposits that were discovered by geophysical studies. In nonmetallic resources, Missouri is the leading State in barite production and is an important supplier of stone, cement, and clay products. Large resources of high quality limestone and dolomite, of silica sand, and of a variety of types of clay, support a growing group of industries that together form the most valuable segment of the mineral industry of the State. Ample resources of coal provide a smaller but growing part of the economy. Active exploration for additional deposits and development of all these resources have had unusual success in the present era of growing demand for mineral products.

UNITED STATES AND WORLD ENERGY RESOURCES

Estimates of United States and world energy resources have been summarized by V. E. McKelvey and D. C. Duncan [3] in categories ranging from reserves in deposits minable at present prices to submarginal and undiscovered but probable resources that may become usable in the future through further exploration and technologic advance. As appraised in this framework, domestic resources of the fossil fuels of the types now considered usable contain 950×10^9 bbl to more than 22×10^{12} bbl of oil equivalent, and, if very low grade organic-rich deposits are included, the potential may be nearly 350×10^{12} bbl of oil equivalent. World resources contain about 3.9×10^{12} to more than 80×10^{12} bbl of oil equivalent, and if very low grade resources are considered the potential may be about 4.3×10^{15} bbl.

The energy potential of uranium resources in the United States ranges from about 35×10^9 to more than 48×10^{15} bbl of oil equivalent. The larger figure assumes the use of low-grade ore and the successful development of a breeding process. The energy potential of world uranium resources similarly ranges upward from 58×10^9 to about 850×10^{15} bbl of oil equivalent. The energy potential of thorium resources of the United States ranges from 1.2×10^{12} to 72×10^{15} bbl of oil equivalent, and that of the world from 8.3×10^{12} to about 1.2×10^{18} bbl. If nuclear fusion can be controlled for power generation, the potential energy from resources of deuterium and lithium-6 are orders of magnitude larger than the fissionable mineral resources. Deuterium alone contains potential energy of 1.3×10^{21} bbl of oil equivalent. Water power, geothermal energy, solar energy, and tidal power also represent large potential sources.

The almost staggering contrast between the magnitude of known reserves usable at present prices and potential resources usable only at higher prices or with more advanced technology underscores the critical importance of research, exploration, and development in meeting future needs.

BAUXITE RESOURCES OF THE WORLD

A revised estimate of the world's bauxite resources by S. H. Patterson (r1006) [4] shows that reserves total about 5.8×10^9 tons. Additional potential bauxite resources, which include low-grade and unfavorably located deposits as well as deposits that lie at depths below the limits of profitable mining, approximate 9.6×10^9 tons. Reserves of bauxite in the United States are less than 1 percent of the world total, and domestic ore would last less than 5 years at the current rate of con-

[1] U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, 1967, Mineral and water resources of Missouri: U.S. Cong., 90th, 1st sess., Senate Doc. 19, 399 p., illus., tables. [Published August 1967]

[2] See note opposite page A1 for explanation of reference notations.

[3] V. E. McKelvey and D. C. Duncan, 1966, Provisional estimates of fossil-fuel resources of the United States [text table 3–1, p. 91], *in* A. B. Cambel and others, Energy R & D and national progress: Prepared for Interdepartmental Energy Study by Energy Study Group, Washington, U.S. Govt. Printing Office, 437 p.

[4] See note opposite page A1 for explanation of reference notations.

sumption if foreign sources were cut off. However, the United States has considerable potential bauxite resources that could be utilized at higher costs than those currently prevailing. Very large potential resources of aluminum also occur in aluminous saprolite, high-alumina clay, aluminous shale, aluminous phosphate rock, igneous rock, and dawsonite-bearing oil shale.

BASE AND FERROUS METALS

LEAD AND ZINC

Three stages of sphalerite deposition recognized in eastern Tennessee deposits

Sphalerite has been deposited in three distinct stages in eastern Tennessee zinc deposits, according to Helmuth Wedow, Jr. The oldest sphalerite, stage 1, consists of banded botryoidal coatings of brown high-iron sphalerite on rubble in the lower parts of breccia bodies. Sphalerite of stage 2, which constitutes the bulk of the commercial ore, is the honey-yellow variety that formed chiefly in open spaces and as fracture fillings both in the rubble and in crackle breccias. The walls of fractures cutting stage 1 sphalerite commonly are bleached and the fractures filled with stage 2 sphalerite, pyrite, and dolomite. The latest and most restricted sphalerite, stage 3, is yellow to yellow orange and is similar to the sphalerite in vein deposits of central Tennessee and Kentucky.

Mineralogy of cavity fillings in eastern Tennessee deposits

Petrographic studies by J. L. Jolly, A. V. Heyl, and M. B. Brock, of the fine-grained red, green, and varved white cavity fillings associated with lead-zinc ore deposits in eastern Tennessee indicate that the fillings contain comparable mineral assemblages that may have been formed at different times. The cavity fillings consist mainly of debris and residue from the host limestone and dolomite, which is chiefly illite clay and minor amounts of quartz and microcline. No materials of volcanic origin, such as bentonite, were found. The red fillings consist chiefly of fragmental dolomite with secondary overgrowths, quartz, rounded microcline, rounded mixed-mineral pebbles, late interstitial illite (less than 2 percent), and sparse replacement sphalerite. The red color is caused by late-stage impregnations of specular and earthy hematite. The green fillings contain angular fragments of greenish iron-stained ferroan dolomite, chert, sparse clay, and subhedral feldspar. The light-colored varved fillings, which commonly exhibit a well-defined graded bedding, consist mainly of detrital dolomite cemented by chert, dolomite, sphalerite, and sparse clay. Sphalerite also occurs as grains, as cross-cutting veinlets, as large replacement patches parallel to varve planes, and as replacements of detrital dolomite, reflecting its size, shape, and texture. No sphalerite overgrowths on detrital sphalerite grains were observed.

MOLYBDENUM

Anomalous rhenium content of molybdenum ores, and association of molybdenite with copper

Unsuspected concentrations of rhenium in molybdenum ores have been found by R. U. King by means of a new analytical method for determining rhenium in the presence of molybdenum that is currently being developed by the Geological Survey. Concentrations of about 400 ppm Re were found in samples of molybdenite from the Patagonia Mountains, Santa Cruz County, Ariz., and as much as 600 ppm Re was confirmed in ore from the Copper Creek district, Pinal County, Ariz. A sample of molybdenite collected by D. F. Crowder (r0990) during a reconnaissance survey of the Devil Canyon–Bear Canyon primitive area, Los Angeles County, Calif., contains more than 1,000 ppm Re. These data are fragmentary but suggest an emerging areal pattern of rhenium concentration that has not thus far been observed elsewhere in comparable deposits in Wyoming, Colorado, and northern New Mexico.

Regional studies of the geochemistry of molybdenite also show a pattern with respect to copper in porphyry-type deposits. The ratio of copper to molybdenum in ore deposits in Nevada, Utah, Arizona, and southern New Mexico is high, whereas this ratio is low in deposits in the Rocky Mountains area of Colorado and northern New Mexico.

MANGANESE

Deposits of hydrothermal manganese oxides

Following an extensive review of the published literature and careful study of a wide variety of samples from stratified deposits of manganese minerals, D. F. Hewett has found confirmation of a genetic relationship between vein deposits of manganese, the manganese oxide deposits in hot-spring aprons, and beds of high-grade manganese oxide in stratified rocks. It is now apparent that most of the manganese in the large stratified deposits of the oxides and carbonates of manganese was derived from hydrothermal solutions from depth, probably from a volcanic source. Only small amounts of manganese in these important sources of maganese ore probably originated from the decay of rocks on the lands adjacent to the large marine and continental basins in which the deposits occur.

IRON

Drill cores reveal details of iron-formation stratigraphy in Palmer basin, Michigan

Detailed study of drill cores from the south-central part of the Palmer basin, southeastern part of the Marquette iron range, Marquette County, Mich., by J. E. Gair reveals that clastic-rock interbeds make up 3 to 6 percent of iron-formation that is 400 to 700 feet thick. Several hundred beds less than 1 inch thick are rather evenly distributed vertically throughout the iron-formation, whereas beds 1 to 50 feet thick are irregularly distributed. The source area of these clastic sediments was south of the present Palmer basin; periodic uplift along faults that delimit the southern margin of the basin are believed to have accelerated the influx of clastic sediments.

Taconite occurrence in Montana

Geologic mapping and magnetometer surveying by W. N. Kelly, Jr., in the Woods Creek area, Ravalli County, Mont., have delineated a 30- to 40-foot-thick bed of taconite-type iron-formation along a strike length of nearly 2 miles. The iron-formation and associated metasedimentary beds, which are of Precambrian age, are folded into a major synform that plunges moderately westward. The formation probably is too thin and of too limited extent to be of economic significance at the present time.

HEAVY METALS

GOLD

Gold anomaly at Cortez, Nev.

Geochemical study of carbonate rocks in the lower plate of the Roberts Mountains thrust fault near Cortez, Lander County, Nev., by R. L. Erickson and others (r0067) has revealed anomalous amounts of gold (as much as 3.4 oz per ton) and mercury in an area previously established to have anomalous amounts of arsenic, antimony, and tungsten. The area was being actively explored by private industry in 1966–67.

Gold and other metals in altered dacite at Goldfield, Nev.

About 280 samples of intensely altered dacite were collected by J. P. Albers and R. P. Ashley from large, recently made cuts across the Combination-January vein in the Goldfield district of southwestern Nevada. This vein in the past yielded gold ore at depths of 50 to 150 feet; the present samples were mostly from depths of 20 to 30 feet. Atomic-absorption analyses for gold showed concentrations of as much as 30 ppm. The samples are enriched in lead, silver, copper, molybdenum, bismuth, and zinc, and most are depleted in beryllium, manganese, cobalt, nickel, and yttrium, relative to the unaltered dacite. Preliminary examination of rocks with high gold content indicates that some, if not all, of the gold is free gold. Lead, silver, and bismuth correlate positively with gold; lead shows the most positive correlation. Results are not yet available for arsenic and mercury.

Incomplete data from geochemical samples taken at 500-foot, or closer, intervals over the entire area of altered rocks at Goldfield (about 17–18 sq mi) show lead anomalies with coincident scattered high silver, bismuth, and molybdenum values.

Gold content of Precambrian rocks, southwestern Colorado

All samples of Precambrian rocks collected by Fred Barker in the southwestern part of the San Juan Mountains in southwest Colorado contain less than 1 ppm Au. These rocks include the Vallecito Conglomerate, which is more than 1,700 million years old, and conglomerate and quartzite of the Uncompahgre Formation, which was deposited, folded, and metamorphosed between 1,700 million and 1,475 million years ago. Clasts in these conglomerates indicate that rocks of the source areas included quartzite, chert, argillite, jasper, and magnetic iron-formation.

Fossil placers in Montana and Idaho

The recognition in east-central Idaho and southwestern Montana of drainage systems that have been reversed or modified in late Cenozoic time suggests that there could be gold placer deposits in this region. Such placers would not be related to present drainage but to the drainage that prevailed before Pleistocene faulting, tilting, and drainage readjustment. Southwestern Montana particularly includes many mining districts from which gold-bearing alluvial gravels could have been derived, and E. T. Ruppel suggests planning prospecting by analysis of late Cenozoic faulting and tilting, and by reconstruction of the late Cenozoic drainage system.

Lead-isotope data and occurrence of ore deposits

Research by R. S. Cannon and A. P. Pierce has produced data of interest to those concerned with the search for gold. They have discovered evidence that ore deposits have been formed chiefly during certain long spans of geologic time. Model ages interpreted from isotopic analyses of ore leads from different continents suggest that the earth has been subject to three such major metallogenetic eras: era A corresponding to Phanerozoic (Paleozoic, Mesozoic, and Cenozoic) time, era B in mid-Precambrian time, and era C early in Precambrian time. Metallogenetic eras in which ores were formed in relative abundance evidently correspond with times of relative crustal activity, separated by times of relative quiescence of the earth's crust.

They have observed further that ore deposits of era A occur predominantly in Phanerozoic host rocks; those of era B predominantly in Precambrian host rocks, many of which are known to be 1,000 million to 2,000 million years old, and those of era C in Precambrian rocks which, so far as is known, are more than 2,000 million years old.

World resources of the various metals are quite unequally distributed among ore deposits of the three major metallogenetic eras. Cannon and Pierce have categorized world lead resources and world gold resources in such terms. Much less than 1 percent of world lead resources occurs in deposits of era C, about 30 percent in deposits of era B, and about 70 percent in era A. World gold resources, on the other hand, have a quite different pattern of distribution. More than 50 percent of known gold resources are in Precambrian deposits that probably represent metallogenetic era C.

Ore leads in gold deposits of the United States have so far scarcely been tested by lead-isotope analysis. From the scant evidence so far available, however, the known gold resources of the United States do not fit the worldwide pattern described above.

Zoning in lode deposits, Fairbanks district, Alaska

Lode deposits in the eastern part of the Fairbanks district in the vicinity of Pedro and Gilmore domes lie along three easterly-trending belts parallel to the regional strike of the metamorphic rocks and the long axes of quartz monzonite and quartz diorite intrusive bodies. R. M. Chapman and R. L. Foster report that the northernmost belt has mainly deposits of scheelite, the middle belt contains sulfide deposits of lead, silver, and antimony with some gold, and the southern belt has largely gold-quartz deposits.

Possible large low-grade gold deposit at Cripple Creek, Colo.

Samples of surface rocks collected by G. B. Gott and others (r1449) from an area 3,800 feet long and 500 feet wide near the Cresson mine in the Cripple Creek district of Teller County, Colo., contain an average of 2.5 ppm Au. If these samples are representative, a large body of rock may be available for mining by low-cost surface methods.

Arsenic as indicator of gold, Atlantic City district, Wyoming

W. C. Prinz has found that residual soils near gold-bearing quartz veins at Atlantic City, in Fremont County, Wyo., contain as much as 80 ppm As, but that the average is only 15 ppm and that soils near some veins contain no detectable arsenic (<10 ppm). He concludes therefore that geochemical exploration for gold using arsenic as an indicator element would not be entirely successful. Soils above some apparently barren Precambrian graywacke and schist contain 10 to 30 ppm As, and 8 out of 50 samples of bedrock beneath these soils contained detectable gold (>0.1 ppm).

Possible ore controls at Carlin, Nev.

Ore bodies of the Carlin gold mine northwest of Carlin in northeast Nevada, appear to be at or near intersections of steeply dipping faults with the contact between the Devonian "Popovich" limestone (Hardie, 1966) [5] and the underlying shale and siltstone of the Roberts Mountains Formation (Silurian). A. S. Radtke believes that ore solutions may have risen along the faults, spread laterally into the Roberts Mountains Formation, and ponded below and in places against the overlying limestone. The limestone is extensively altered, but most ore found to date is in shale and siltstone. The ore bodies show little if any relation to the Roberts Mountains thrust fault.

Gold and other metals in South Mountains, N.C.

Work to date by J. W. Whitlow in the South Mountains of west-central North Carolina indicates that the placer gold mined in the area came mainly from quartz veins generally less than one-quarter inch thick. Several veins close enough together to mine as a unit were found in a few places in saprolite, but none was found in fresh rock.

Quartz veins north of Morganton, in Burke County, that contained economic amounts of gold have been mined out and abandoned. Galena and copper minerals, which were in some of the veins, apparently were not mined; however, some galena may have been recovered and not reported. Debris at the Baker mine contains tungsten and molybdenum minerals.

The valley fill of most streams between Lenoir and the Broad River north of Rutherfordton, in west-central North Carolina, contains some placer gold. The gold content of fill along the large streams, however, is likely to be very low and not economic.

[5] B. S. Hardie, 1966, Carlin gold mine, Lynn district, Nevada *in* Papers presented at AIME Pacific Southwest Mineral Industry Conference, Sparks, Nevada, May 5–7, 1965: Nevada Bur. Mines Rept. 13, pt. A, p. 73–83.

Wool as a collector of gold from dilute solutions

Henry Kramer has determined that wool is an effective agent for the collection and concentration of gold from dilute solutions. This could become an important means for study of and prospecting for gold. Radiotracer studies of gold uptake from 20 cc of 1.5M HCl solution by a small column of wool (3 inches by ¼ inch) show 100-percent recovery of 0.1 mg (0.5 ppb) concentrations. The uptake has been determined to be an exchange mechanism for which isotherms were determined at varying acidities. The exchange capacity from pH 0 to 2 is 11.3 ± 0.2 mg Au per g of wool; at higher pH, gold breaks through immediately.

Recovery of gold from tapwater at concentrations of 0.05, 0.5, and 5.0 ppb Au was quantitative.

MERCURY

Distribution of mercury in Navajo Sandstone, Colorado Plateau

Trace amounts of mercury in 94 samples of Navajo Sandstone (Jurassic and Triassic?) from 29 localities in the Colorado Plateau region are distributed in a geologically significant pattern, according to R. A. Cadigan. Values range from less than 0.010 to 0.650 ppm. The average (log mean) is 0.038 ppm. Samples with highest mercury content (0.650 and 0.500 ppm) are from Beclabito dome, a structure in northwestern San Juan County, N. Mex. Other high values occur in San Miguel and Montezuma Counties, southwestern Colorado, and in San Juan County, Utah.

Contours suggest a halo around the western side of the mineralized region of the San Juan Mountains, in southwestern Colorado, resulting possibly from hydrothermal activity related to ore deposition in the San Juan Mountains or perhaps to movement of ground water. The Beclabito dome structure and Ute Mountain to the northeast in Montezuma County possibly lie on a southwestern salient of the San Juan structures and thus warrant closer examination for indications of economically significant heavy-metals mineralization.

The southwestward depositional trend of the Navajo as interpreted from orientation of bedding structure suggests that the mercury concentrations do not reflect source area mineralization. The trend suggested by the contours in the Four Corners area may be in general agreement with the direction of movement of ground water or aquifer drainage from the mineralized areas to the east. Additional data are needed to determine whether concentrations of high values result from ground water or hydrothermal activity.

Less conspicuous concentrations of mercury were found in the Cedar Mountain–San Rafael Swell area, Carbon County, Utah, and in the Antimony Creek area, Garfield County, Utah.

PLATINUM

Platinum and other heavy metals in Medicine Bow Mountains, Wyo.

Samples of waste material from mining and milling operations at the New Rambler mine near Holmes, in the Medicine Bow Mountains of south-central Wyoming, average about 1 ppm platinum metals, 0.7 ppm Au, 6 ppm Ag, and 0.3 percent Cu. According to P.K. Theobald, about 50,000 tons of such material is present.

SILVER

Silver-bearing manganese oxide at Silver Cliff, Colo.

Studies of the silver ores of the Silver Cliff and Rosita mining districts by F. A. Hildebrand show that notable amounts of silver associated with manganese remain in outcrops and dumps, particularly in the Silver Cliff district of Custer County. The silver mineral mined was thought to be cerargyrite (silver chloride) but is actually bromargyrite (silver bromide). The silver-bearing manganese oxide mineral is argentian cryptomelane, a new variety heretofore undescribed, which contains as much as ½ to 1 percent Ag. It also contains as much as 5 or 6 percent Pb, Zn, and Ba, and lesser amounts of Bi, Sb, Cu, As, V, Mo, Cd, and Co. During the early days of mining, silver was extracted principally by amalgamation which removed only the silver bromide; thus the silver-bearing manganese oxide could not be treated and was rejected.

Silver and mercury geochemical anomalies, Nevada and Utah

According to H. R. Cornwall and others (p. B10–B20),[6] chemical analyses of residual soils and rocks from the Comstock and Tonopah districts of southwestern Nevada and the Silver Reef mining district of southwestern Utah clearly delineate areas of the principal silver mines in all districts. Mercury anomalies show the same pattern at Tonopah and Silver Reef, but in the Comstock district mercury values are outside the main silver-gold mining area. This suggests horizontal zoning from a central silver-gold area outward to a mercury area, and that if similar zoning occurs vertically, several mercury anomalies may be underlain by silver-gold mineralization.

Silver, bismuth, and tin in sulfide deposits of New Hampshire and Maine

Spectrographic analysis of galena and sphalerite from mineral deposits in eastern New Hampshire and

[6] See note opposite page A1 for explanation of reference notations.

southwestern Maine indicates a high content of silver, bismuth, and tin. The mineral deposits, which have been the subject of a reconaissance study by Dennis Cox and John D'Agostino, are quartz veins and silicified breccias containing galena, sphalerite, arsenopyrite, chalcopyrite, and locally abundant pyrite and pyrrhotite. The overall trend of the deposits suggests an association with the intrusive rocks of the White Mountains magma series. The deposits are small, but they define a distinct metallogenic province that constitutes a target for geophysical and geochemical exploration for heavy metals.

TIN

Possible tin ore shoot at Black Mountain, Alaska

According to C. L. Sainsbury and J. C. Hamilton (p. B21–B25), veins at Black Mountain in the western Seward Peninsula of Alaska contain anomalous amounts of Be, Cu, Bi, and Mo, elements characteristic of tin deposits. By analogy with ore-bearing veins at the Lost River tin mine, 20 miles to the west, where the higher levels of a tin ore shoot contain only small amounts of tin and other rare metals, the veins at Black Mountain may contain an ore shoot at depth.

LIGHT METALS AND INDUSTRIAL MINERALS

ALUMINUM

Dawsonite deposits in northwest Colorado

Deposits of dawsonite ($NaAl(OH)_2CO_3$) in the Piceance basin, northwest Colorado, provide an enormously large potential resource of aluminum. The mineral is found in oil shale in the Green River Formation of Eocene age. It occurs both in outcrops and at depth. Outcrop samples collected by D. A. Brobst and J. R. Dyni from the northern rim of the Piceance basin (near Cathedral Bluffs, lower Piceance Creek, and Rio Blanco) contain dawsonite irregularly distributed in a vertical stratigraphic interval about 600 feet thick that lies between the base of the Parachute Creek Member and the Mahogany marker bed. X-ray diffractograms indicate that the dawsonite content in these samples ranges from trace amounts to about 10 percent. Subsurface samples from J. T. Juhan core 4–1, studied by Dyni and R. J. Hite, contain disseminated dawsonite throughout a 628-foot-thick interval of oil shale. Dawsonite content in this interval, as determined by X-ray diffraction methods, averaged about 11 percent. Associated minerals include quartz, dolomite, K-feldspar, albite, and nahcolite. Experimentation by Dyni and Hite on dawsonite-bearing oil shale indicates that dawsonite reacts to form a water-soluble sodium aluminate at temperatures in the range of those used in some oil-retorting processes.

EVAPORITES

United States borate reserves

The entire United States production, and nearly 90 percent of world production of borate minerals, comes from deposits in California. A review of deposits in that State by W. C. Smith (r1902) shows that production in the 5-year period 1960–64 was equivalent to 350,000 tons of B_2O_3 per year. It had a value of nearly $52 million per year and accounted for nearly 10 percent of the total value of California's annual mineral production (exclusive of petroleum products). Reserves in the two main producing deposits—brine at Searles Lake and borax at Kramer—are large enough to sustain production at present rates of extraction for 50 to 100 years. Colemanite deposits provide potential borate resources that are large; a small production now comes from these deposits, but large-scale mining would require more favorable economic conditions.

New rare-earth saline mineral from Utah

A new rare-earth mineral (calcium rare-earth borate-carbonate) has been found by O. B. Raup and others (p. C38–C41) in the marine evaporites in the Paradox Member of the Hermosa Formation of Pennsylvanian age in southeastern Utah. This is the first known occurrence of any rare-earth mineral from marine evaporites. The mineral occurs in nodules in a 6-inch zone in anhyrite which immediately overlies the potash deposit in the Cane Creek mine of the Texas Gulf Sulphur Co. near Moab, Utah. The stratiform occurrence of this mineral and its relation to the host rock indicate that it is a diagenetic mineral and is most likely the result of rare-earth elements concentrated from either sea water or the sea water–sediment system.

PHOSPHATE

Phosphate deposits along Atlantic Coastal Plain

The phosphorite deposits of the Atlantic Coastal Plain of the southeastern United States continue to be the major domestic source of phosphate. J. B. Cathcart, in a continuing study of the geologic setting of the deposits, notes that all are in or are derived from rocks of Miocene age, and that all of them are found in basins on the flanks of domes or anticlines that were rising at the time of deposition. Thus the location of these deposits is at least in part structurally controlled.

Investigations in the southern Georgia and northern Florida segment of this area by C. W. Sever, J. B. Cathcart, and S. H. Patterson have shown that as much as 1 × 10^9 tons of phosphate resources may be present over an area 175 miles long and 25 to 50 miles wide. Most of the phosphate occurs in the Hawthorn Formation of early and middle Miocene age, but some also occurs in sandy beds of late Miocene age and in transported deposits of Pliocene age. Most of the recoverable phosphate is of concentrate size; the pebble fraction is minor in amount and too low grade to be a major resource.

Phosphate in Tennessee

A growing awareness of the geologic characteristics and potential value of phosphatic rocks continues to result in the identification of potentially favorable areas, not only in the Atlantic Coastal Plain but in other areas as well. For example, phosphatic rocks previously noted in parts of the Precambrian Ocoee Series in east Tennessee are now reported by Helmuth Wedow, Jr., and R. H. Carpenter (Tennessee Valley Authority) from a total of 12 localities over a strike distance of more than 100 miles. The phosphatic material occurs as thin layers, lenses, or nodules in carbonaceous slates, as a matrix in more massive beds of quartzose or arkosic sandstones, or as clastic fragments up to cobble size in "turbidite" conglomerates. Ten of the localities are in strata of the Walden Creek Group and two are in the Great Smoky Group. Because the phosphatic rock is readily leached by the acidic ground waters of this region, most occurrences found have been in roadcuts. Even at these depths, however, evidence of leaching is prominent. Although none of the phosphorite found thus far in the Ocoee Series is of economic value, its widespread occurrence, the high grade (in excess of 25 percent P_2O_5) of the few fresh specimens available, and the general sedimentary environment of these Precambrian strata suggest a potential that has not been adequately explored.

INDUSTRIAL MINERALS OF SEDIMENTARY ORIGIN

New clay resources in southern Pennsylvania

During 1966, after more than 125 years, the clay-mining industry in Allegany County, Md., came to a close, and nearby refractory companies are now dependent upon the clay resources of southern Pennsylvania. A program of study by J. W. Hosterman in eastern Fayette and Somerset Counties, Pa., has included evaluation of four underclay beds in the Allegheny Group of Pennsylvanian age—the Brookville, Clarion (Mount Savage), Lower Kittanning, and Upper Kittanning—as potential sources of refractory-grade clay. The best grade underclay bed contains flint clay and semiflint clay, and occurs on both limbs of a very broad syncline; its eastern limb crops out along the western slope of the Allegheny Mountains, and its western limb crops out along the eastern slope of Laurel Hill. A few beds contain diaspore, a high-alumina mineral which has not been previously recognized in this area.

Diagenetic zeolite and potassium feldspar in Oregon

Pliocene tuff beds rich in diagenetic zeolite and potassium feldspar were found by G. W. Walker and D. A. Swanson in bluffs on the margin of the Malheur National Wildlife Refuge and just east of Harney Lake, southeast Oregon. Some beds contain more than 90 percent zeolites, including principally clinoptilolite and heulandite, and lesser amounts of phillipsite and erionite. A few thin beds contain about 60 percent potassium feldspar; X-ray diffraction indicates that the feldspar is orthoclase with about 98 percent $KAlSi_3O_8$.

BARITE

Age of Arkansas barite deposits

Many geologists have postulated that the bedded barite deposits in the Paleozoic rocks of southwestern Arkansas were formed during a cycle of igneous activity in early Late Cretaceous time, even though most of the deposits are many miles from known igneous rocks of Cretaceous age. From the information gathered by D. A. Brobst, however, it seems that the barite deposits may have been formed prior to the Ouachita orogeny of late Paleozoic age. The new evidence consists of folded and crushed beds of barite in the Stanley Shale (Mississippian age), in the vicinity of Fancy Hill, Montgomery County, which appear to have been deformed during displacements along nearby faults. These faults are on the south side of the Ouachita Mountains and displacements along them are generally attributed to the Ouachita orogeny in late Paleozoic time. No subsequent major episodes of rock deformation have been recognized in the region, although it is possible that the barite deposits were emplaced later and subsequently deformed by an unrecognized episode of later movements along these older faults.

LIGHTWEIGHT AGGREGATES

Vermiculite deposits

Vermiculite is generally believed to have formed by alteration of biotite, chlorite, or phlogopite, but there is lack of agreement on whether the alteration is entirely hydrothermal, entirely the result of weathering, or a combination of both. In a review of the literature on the formation and habits of vermiculite deposits, A. L. Bush has tentatively concluded that there are no significant occurrences of this mineral that lie below past or present zones of weathering. If vermiculite is virtually confined to the zone of weathering, as thus seems possible, current resource estimates could be too high.

RADIOACTIVE MINERALS

URANIUM

Uranium deposits in Morrison Formation of Utah and Colorado

In reporting the results of a comprehensive study of uranium deposits in the La Sal quadrangle, eastern Utah and western Colorado, W. D. Carter and J. L. Gualtieri [7] point out that most of the known and the largest deposits are in a belt 6 miles long and as much as 3,000 feet wide which trends N. 70° E. mostly on the north side of La Sal Creek. The belt is in a similarly elongate composite lens of variably light-brown, light-gray, or white sandstone near the top of the Salt Wash Sandstone Member of the Morrison Formation of Jurassic age.

More deposits may occur in a possible eastward extension of this belt into areas where the Salt Wash Sandstone Member is covered by younger rocks. Also, the distribution of some of the scattered deposits elsewhere in the area and the characteristics of the rocks associated with them suggest that other, similar belts may be present.

Uranium and vanadium deposits in Emery County, Utah

C. C. Hawley and others [8] report that uranium and vanadium deposits in the Temple Mountain district, Emery County, east-central Utah, are largest and most numerous in a 9,000-foot-long northeast-trending belt within the Moss Back Member of the Chinle Formation of Triassic age, a few thousand feet southeast of South Temple Mountain. Lesser deposits are in and peripheral to areas of collapsed rocks mainly between North and South Temple Mountains.

Most of the ore bodies in the district are tabular or roll-form masses of mineralized rock. They are thought to have been formed along the planar surfaces and marginal edges, respectively, of bodies of migrating carbonated ground water. These solutions displaced preexisting petroleum, mildly altered (bleached) the rocks they traversed, and deposited U, V, Se, As, and minor amounts of Cr, Cu, Pb, and Zn to form asphaltite-rich mineral deposits.

Carbon dioxide-bearing aqueous solutions are thought to have been introduced into the Moss Back Member and other strata through the collapse structures; to have transported U, Se, and As from sources relatively distant from the deposits; and to have redistributed V and Cr from heavy minerals in the host rocks in the process of alteration.

Possible redistributed uranium deposit, San Juan basin, New Mexico

Several investigators have noted a coincidence between the position of uranium deposits and more intensely faulted parts of the southern San Juan basin mineral belt, McKinley and Valencia Counties, N. Mex. This relation has been puzzling because the primary uranium deposits—also referred to as trend deposits—are thought to be related in age to the stage of diagenesis of the enclosing rocks of Mesozoic age, whereas the faults are thought to be mid-Tertiary and later in age. Studies by H. C. Granger and E. S. Santos now suggest an explanation. Conjugate fault systems tended to impede and to divert meteoric waters that once moved downdip, oxidizing and destroying the primary ore and redistributing its constituents. Extensive deposits of redistributed ore formed in places where faults that cut primary ore impeded or guided the flow of the ground water. In parts of the mineral belt relatively undisturbed by faults, oxidized host sandstone may be barren of ore deposits only because they have been removed rather than not being deposited originally. Perhaps the distal ends of tongues of the oxidized rock are bordered by roll-type uranium deposits far downdip from the trend of the mineral belt. If such deposits exist, they would be buried much more deeply than the deposits now being mined.

Paleodrainageways and uranium deposits in Wyoming

A detailed study of the paleotopography and paleodrainage patterns in the Shirley basin area and similar but cursory study of other uranium-bearing areas in Wyoming, has been made by E. N. Harshman. He postulates that the position of the uranium deposits in the basins of these regions may be related to the position of the major streams that carried sediments from the surrounding uplifts into the basins. Factors tending to localize the deposits in the major paleostream channels would include favorable lithologic characteristics of the host material as well as a subsequent flow of the ore-bearing solutions through that material. Many of the major paleodrainageways are identifiable on geologic maps, even of small scale.

Transport and deposition of uranium, Black Hills, S. Dak.

C. G. Bowles has used analyses of water supplied by W. E. Chenoweth of the U.S. Atomic Energy Com-

[7] W. D. Carter and J. L. Gualtieri, 1965, Geology and uranium-vanadium deposits of the La Sal quadrangle, San Juan County, Utah, and Montrose County, Colorado: U.S. Geol. Survey Prof. Paper 508, 82 p. [1966]

[8] C. C. Hawley, D. G. Wyant, and D. B. Brooks, 1966, Geology and uranium deposits of the Temple Mountain district, Emery County, Utah: U.S. Geol. Survey Bull. 1192, 154 p.

mission from 32 wells at the margin of the southern Black Hills, western South Dakota, in an endeavor to refine the concept of the role of meteoric waters in deposition of uranium in this area. The hypothesis proposed is that, since late Eocene time, highly mineralized calcium sulfate-type ground water has derived minor amounts of uranium from multiple sources such as anhydrite, dolomite, shale, volcanic ash, and granite. The ground water has migrated downdip to the margin of the Black Hills where, under artesian pressure, it has risen along faults and fractures and through pipe (solution collapse) structures into the Inyan Kara Group of Early Cretaceous age. A reducing environment in the favorable host rocks, which was maintained by hydrogen sulfide and locally perhaps by other reducing agents, precipitated uranium from solution before the ground water discharged into major drainageways marginal to the Black Hills.

Ferroselite and uranium, Crook County, Wyo.

Ferroselite ($FeSe_2$), not previously recorded in uranium deposits in the Inyan Kara Group of Cretaceous age in northeast Wyoming, has been noted by A. P. Butler, Jr., in a selenium-rich sample from the Hauber mine in Crook County. The sample represents a part of the host sandstone inside of and adjoining the interval of maximum uranium content defined by other samples in the same set. This position corresponds with the position of ferroselite in selenium-rich zones in uranium deposits in Tertiary rocks in the Shirley basin (E. N. Harshman, r0102) and the Powder River basin (H. C. Granger, r0098), Wyoming.

Elements accompanying uranium in coal, Cave Hills, S. Dak.

Using various statistical methods, G. N. Pipiringos (r0338) has compared amounts of various elements determined spectrographically with the content of uranium in samples of impure coal and coaly carbonaceous rocks of Paleocene age from the Cave Hills area, northwest South Dakota. The results of this study indicate that U, Fe, P, As, Be, Ge, La, Mo, Nd, Sn, V, Y, Yb, and Zr, and possibly Ba, Cu, Ni, Pb, Sc, and Sr, were absorbed by coaly material from circulating ground water after coalification and before late Pleistocene time. Other elements detected in coal—Si, Al, Na, K, Ti, Ag, Cr, Ga, and possibly Mg—were probably original components of admixed mineral impurities.

Geologic maps of important producing areas in New Mexico and Wyoming

Two groups of geologic maps show, at a scale of 1:24,000, the distribution of the exposed rocks and the structure in much of the two principal uranium mining areas in the United States. Four sheets represent a large part of the Ambrosia Lake area, McKinley and Valencia Counties, N. Mex.[9-12]; three others represent parts of the Gas Hills area, Fremont County, Wyo. (P. E. Soister, r0668, r0669, r0670).

GAMMA-RAY ANOMALIES

Numerous gamma-ray anomalies have been noted by D. H. Eargle in logs of drill holes that penetrate rocks of Miocene and Oligocene(?) age in Duval, County, south Texas. The anomalies, some at a depth of as much as 2,000 feet, are generally in channel-filling sands surrounded by tuffaceous silt and sand.

MINOR ELEMENTS

New analyses of the distribution of rare earths in phosphorites by Z. S. Altschuler and others (p. B1–B9) reveal unique fractionation in apatite of marine origin, paralleling the fractionation of rare earths in sea water. The essential characteristic of the rare-earths suite for both apatite of marine origin and sea water is a marked depletion in cerium. Apatites of igneous and subaerial origin do not show this fractionation, a feature which may furnish a means of distinguishing terrestrial phosphate deposits from those of marine origin.

Marine phosphorites contain a large potential new resource of rare-earth elements for American industry. Estimates based on current production of wet-process phosphoric acid show 4,000 to 5,000 tons of rare earths annually available for recovery from this source alone. Moreover, the rare earths from these phosphorites are relatively rich in yttrium and the intermediate group of rare-earth elements, which are of special importance in nuclear and electronic technology.

ORGANIC FUELS

COAL

Coal resources and special maps in southwestern Pennsylvania

Coal reserves of four 7½-minute quadrangles near Washington, Pa., have been estimated by H. L. Berry-

[9] E. S. Santos, and R. E. Thaden, 1966, Geologic map of the Ambrosia Lake quadrangle, McKinley County, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–515.

[10] E. S. Santos, 1966, Geologic map of the San Lucas dam quadrangle, McKinley County, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–516.

[11] E. S. Santos, 1966, Geologic map of the San Mateo quadrangle, McKinley and Valencia Counties, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–517.

[12] R. E. Thaden, E. S. Santos, and E. J. Ostling, 1966, Geologic map of the Goat Mountain quadrangle, McKinley County, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–518.

hill, Jr., S. P. Schweinfurth, and B. H. Kent. The Pittsburgh bed contains 1,187.2 million tons of measured reserves remaining, and the Waynesburg bed contains 574.8 million tons; of 7 coal beds in the area, these are the only beds currently being mined.

Pinchout of Gladeville Sandstone mapped in Lee County, Va.

Recent mapping by R. L. Miller shows that the Gladeville Sandstone of Pennsylvanian age, a key bed separating the coal-bearing Wise and Norton Formations (also Pennsylvanian) in the southwest Virginia coal fields, pinches out in the eastern part of the Pennington Gap quadrangle. The new mapping also demonstrates that coal beds of minable thickness continue across the Keokee and Pennington Gap quadrangles, and that beds shown on small-scale earlier maps of this area are either mislocated, too thin to mine, or absent.

Previously unreported coal deposit noted in northern Rio Arriba County, N. Mex.

The Tierra Amarilla coal field of Rio Arriba County, N. Mex., as defined by C. H. Dane and E. R. Landis, is a small area of about 20 square miles underlain by the coal-bearing Upper Cretaceous Mesaverde Group at the boundary of the Chama basin and the southern extension of the San Juan Mountains. The Menefee Formation of the Mesaverde Group contains as many as 9 coal or carbonaceous shale beds; most are lenticular and less than 14 inches thick. However, coal beds near the base are more persistent and reach a maximum measured-bed thickness of 49 inches. The coal, which is of subbituminous-A or high-volatile bituminous-C rank, has been mined for local domestic use and may be of value in the future, though the total resources of the field value are probably small.

York Canyon coal mine in operation in Colfax County, N. Mex.

C. L. Pillmore reports that coal is being mined and processed at a large new coal mine and preparation plant in the Raton coal field in York Canyon. The coal is in the Raton Formation of Late Cretaceous and Paleocene age. Present daily production is about 3,400 tons. The Raton contains one of several beds of bituminous coal shown on the Catskill SW and NW 7½-minute quadrangles, which were put on open file by the Geological Survey in 1964 [13] and 1966.[14]

[13] C. L. Pillmore, 1964, Geologic map of the Catskill SW quadrangle, Colfax County, N. Mex.; U.S. Geol. Survey open-file rept., scale 1 : 24,000, one sheet.

[14] C. L. Pillmore, 1966, Geologic map of the Catskill NW quadrangle, New Mexico and Colorado: U.S. Geol. Survey open-file rept., scale 1 : 24,000, one sheet.

Large coking-coal reserves delineated in Colfax County, N. Mex.

Isopach studies by C. L. Pillmore, based on drilling information from private industry, define the extent of two economically important beds of high-quality bituminous coking coal in the extreme western part of the Raton coal field in northern New Mexico. Both beds are in the Vermejo Formation of Late Cretaceous age —one is at the top, the other at the base. The study outlines areas of thickest coal (more than 10 feet in places) and indicates trends to help guide further exploration programs. Thickness of overburden ranges from zero to about 2,000 feet. The two coal beds, each of which is generally more than 5 feet thick, underlie an area of about 40 square miles in the vicinity of Castle Rock Park, and their aggregate indicated reserves total over 425×10^6 tons.

Large reserves of coal mapped in southern Utah

H. D. Zeller reports that geologic mapping of the Dave Canyon, Canaan Creek, Carcass Canyon, and Death Ridge 7½-minute quadrangles south of Escalante, Utah, indicates coal reserves of about 2.5×10^9 tons in a 110-square-mile area. This estimate includes only beds more than 5 feet thick within 2,000 feet of the surface. Most of the coal beds range from 5 to 15 feet in thickness, but 1 bed about 22 feet thick is overlain by less than 250 feet of overburden in an area of about 1 square mile. An analysis by the U.S. Bureau of Mines of a typical coal in the area shows heating values of 10,773 Btu with 7.1 percent ash, 42.8 percent fixed carbon, 38.1 percent volatile matter, 12 percent moisture, and 0.6 percent sulfur.

PETROLEUM AND NATURAL GAS

Oil and gas potential of Atlantic Coastal Plain

In reviewing the regional geology of the Atlantic Coastal Plain and the Continental Shelf, J. C. Maher concludes that Upper Jurassic and Lower Cretaceous rocks offer the most promise for oil and gas production in the Atlantic coastal region. Their combined thickness exceeds 5,000 feet offshore in the Baltimore Canyon trough, in the southeast Georgia embayment, and under the Blake Plateau and Bahama Islands. Marine beds generally regarded as potential sources of petroleum are predominant. The depositional environment, at least in the southern areas, probably favored reef growth. Thick very porous salt-water-bearing sandstone and carbonate reservoirs are numerous. Major unconformities are present at the top and also within the sequence. Three small oil accumulations have been discovered in Lower Cretaceous rocks on the gulf side of Florida.

Possibilities for oil and gas production from Upper Cretaceous rocks under the shelf are good, but are only fair in the Coastal Plain. Potential reservoir rocks seem to extend under the shelf where marine source rocks may be abundant. Rocks of Woodbine and Eagle Ford age appear to be favorable reservoir-source rock-beds whose thickness probably exceeds 2,000 feet offshore. Also, an unconformity at the base of the Upper Cretaceous is important for petroleum accumulation because in places, the basal Upper Cretaceous sandstones of the Woodbine Formation overlap marine Lower Cretaceous rocks. Tertiary rocks along the coast are the least promising for large petroleum accumulations. Although they show very good reservoir and fair source-rock characteristics, they are relatively thin, contain fresh-to-brackish artesian water in much of the area, and crop out in places beneath the sea. In addition, structural features are less distinct than in older rocks, and unconformities and overlaps are regionally less significant.

Petroleum geology of Wyoming

Evidence for long-distance eastward migration of Permian oil in Wyoming has been presented by R. P. Sheldon (r2135). Organic matter originally deposited in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in western Wyoming was probably the source of crude oil in traps in Permian and Pennsylvanian rocks in central Wyoming. This is indicated by the upwelling ocean-current environment of sedimentation, the organic-matter content of the shale, and the similar distribution of trace elements in both the organic-rich shale and the crude oil. The fluids from the Meade Peak were squeezed into Permian and Pennsylvanian conduit rocks by Mesozoic sedimentary loading. Differential loading through sedimentation of the geosyncline in the west, in relation to the craton to the east, along with a steepening of the regional westward dip in the conduit beds owing to this sedimentation, caused the fluids to migrate eastward as much as several hundred miles to the present area of oil traps.

OIL SHALE AND HUMATES

Oil shale in Christian region of northeastern Alaska

I. L. Tailleur, W. P. Brosgé, an H. N. Reiser, with the guidance of native residents, located two occurrences of tasmanite in the Christian region of northeastern Alaska (lat 67½° N., long 145½° W.), thus confirming an earlier report of rich oil shale in this area.[15] The tasmanite is an oil-rich rock that is similar to that on the north side of the Brooks Range (H. A. Tourtelot and others, r1458), and is similarly distributed in small amounts in clay-shale layers associated with varicolored chert and mafic rocks. Samples yielded 60 to 144 gallons of oil per ton, with low amounts of trace elements. The economic potential of the oil shale is limited, but the deposit might serve as a local source for fuel. The tasmanite–chert–mafic rock assemblage in the Christian region indicates a 150-mile eastward extension of this peculiar lithogenetic group from the nearest known occurence on the north slope of the Brooks Range.

Geologic setting of oil-shale deposits

The lithology, depositional environment, and world distribution of oil-shale deposits were recently reviewed by D. C. Duncan (r1424). Three principal lithologic types of oil shale are recognized: carbon-rich shale, siliceous shale, and cannel shale. Major oil-shale deposits were formed in large lakes and on marine platforms and shelf areas. Numerous small deposits were formed in open bodies of water near coal-forming swamps. The major older deposits were formed mostly on marine platforms and generally are low grade. Most of the large younger deposits were formed near the world's Tertiary orogenic belts in large lakes and marine basins that deepened during accumulation of the shale.

Humate deposits of northwestern Florida

Guided by information provided by R. O. Vernon, State Geologist of Florida, V. E. Swanson located several rich humate deposits 30 to 50 miles inland from the coast of northwest Florida at an elevation of about 185 feet. The genesis of this type of humate, as worked out in Choctawhatchee Bay, Fla.,[16] supports Vernon's interpretation that the beds of humate sand indicate former sea-level stands.

MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT

Mineral surveys in primitive areas that are being considered for inclusion in the National Wilderness Preservation System consist of reconnaissance mapping and extensive sampling of bedrock units, drainage areas, and mineralized and nonmineralized geologic structures. To date, 9,928 samples from 19 primitive areas have been analyzed, and 212,160 analytical determinations have been made. The rate of fieldwork in several of the primitive areas has been greatly increased through the use of helicopters. Mineral studies of U.S. Department of the Interior lands have been

[15] J. B. Mertie, Jr., 1929, The Chandalar-Sheenjek district: U.S. Geol. Survey Bull. 810–B, p. 138–139.

[16] V. E. Swanson and J. G. Palacas, 1965, Humate in coastal sands of northwest Florida: U.S. Geol. Survey Bull. 1214–B, p. B1–B29.

confined entirely to wildlife refuges, and have consisted largely of office reviews of available information.

PRIMITIVE AREAS

Mount Baldy Primitive Area, Ariz.

T. L. Finnell and others (r0742) found no evidence of prospecting activity or of significantly mineralized rock in the Mount Baldy Primitive Area of east-central Arizona. The primitive area is underlain by about 3,500 feet of Tertiary and Quarternary volcanic rocks. Locally, it is covered by as much as 450 feet of glacial drift. Samples of the bedrock units and sediment samples from the streams draining the area did not indicate any concentration of metals. A small cinder cone in the north part of the area might yield material suitable for road metal, but its small size and inaccessibility as compared to other cinder cones in the region lessen its potential value. The Coconino Sandstone of Permian age is a potential reservoir for petroleum and natural gas and may be present at depth, but the existence of structural traps is conjectural. No oil test holes have been drilled in the area, but holes drilled 35 miles to the north were not productive.

Pine Mountain Primitive Area, Ariz.

Pine Mountain Primitive Area, in central Arizona, is underlain principally by Precambrian granitic and metamorphic rocks. In the western part of the area, these rocks are overlain by Paleozoic sedimentary rocks and by volcanic rocks of Tertiary age.

No mining has been done within the proposed wilderness area, and no commercially significant mineral deposits are known in it (F. C. Canney and others, r1954). Iron-stained zones, bleached areas, quartz-jasper stringers, and minor shear zones are common in the Precambrian rocks, but samples of materials from these areas contained only traces of metallic minerals. Metal content of stream-sediment samples from the area is at or close to the background level expected of unmineralized rocks. No anomalies suggestive of near-surface metallic-mineral deposits were found.

Sycamore Canyon Primitive Area, Ariz.

Steep cliffs of the Sycamore Canyon Primitive Area, central Arizona, are carved principally in nearly flat-lying sedimentary rocks of Paleozoic and Mesozoic age (L. C. Huff and others, r0070). These sedimentary rocks are capped by basalt flows of much younger age, which form the canyon rims. The rocks locally are faulted and jointed and some of the faults have been intruded by basalt dikes.

No mineral production has been recorded from the area, and the only evidence of prospecting is limited to a few lode claims near the south boundary. No mineral deposits of commercial importance were found in the area, nor did geochemical reconnaissance reveal any anomalous concentrations of metals. Rocks along some faults and dikes are somewhat altered in a few places, but only traces of ore minerals were found in these localities. The chances that valuable accumulations of petroleum exist at depth are slight because the canyon has cut almost to the base of the sedimentary-rock sequence.

Desolation Valley Primitive Area, Calif.

The Desolation Valley primitive area, in northeastern California, includes about 100 square miles of glaciated terrain that extends along the crest of the Sierra Nevada southwest of Lake Tahoe. Intrusive rocks of the Sierra Nevada batholith and metamorphosed roof pendants are well exposed in the area.

F. C. W. Dodge and P. V. Fillo (r1955) describe a small area half a mile south of Gilmore Lake, in the NE¼ sec. 17, T. 12 N., R. 17 E., as containing significant amounts of gold. Metavolcanic rocks in the mineralized zone contain widely spaced veinlets and disseminated grains of gold-bearing sulfide minerals. Of 48 samples taken in an area about 2,000 feet long and 150 feet wide, 15 contained 1 ppm Au or more and few samples contained several parts per million. The richest sample contained 46 ppm Au. Insofar as known from outcrops, the deposit is too low in grade, the gold too erratically distributed, and the area too difficult of access for the deposit to be commercially exploitable. The deposit is promising enough, however, to warrant further exploration.

No evidence was found elsewhere of economic mineral deposits. There is no record of mineral production from the primitive area and no mineral commodities were known in it that could have been mined economically in 1966.

Devil Canyon–Bear Canyon Primitive Area, Calif.

The Devil Canyon-Bear Canyon Primitive Area, in southwest California—also referred to as the proposed San Gabriel Wilderness—is underlain by a variety of massive and gneissic granitoid rocks that are dominantly of igneous origin (D. F. Crowder, r0990). These rocks are cut along the south boundary of the area by the San Gabriel fault, a zone of repeated movement. No significantly mineralized rocks were found in the fault zone or elsewhere. In nearby areas, gold-bearing quartz veins and placer deposits have been prospected and mined, but the few quartz veins observed within the primitive area are barren, and no placer deposits were found. Gravel, stone, and other nonmetallic deposits are either absent, of noncommercial quality, or more readily accessible in nearby areas.

Ventana Primitive Area, Calif.

R. C. Pearson and others (r2029) describe the Ventana Primitive Area, Monterey County, Calif., as consisting largely of gneisses and schists of probable Paleozoic age, intruded by a wide variety of plutonic rocks of Jurassic to Cretaceous age. These crystalline rocks are overlain locally by sedimentary rocks ranging in age from Late Cretaceous to early Miocene. Faults are widespread throughout the region.

No commercially significant mineral deposits are known in the area, and there is no recorded mineral production from it. Locally, the gneisses contain disseminated iron sulfides, and some of these gneisses, as well as the stream sediments derived from them, contain higher than normal quantities of copper, lead, zinc, molybdenum, and vanadium. None of the samples of these materials approached ore in grade. Mercury, chromite, manganese, and asbestos have been mined in nearby areas, but the rock formations containing these commodities are not present in the Ventana Primitive Area. Oil and gas produced from neighboring parts of the California Coast Ranges are obtained from rocks younger than those in the primitive area, and in structural settings more favorable to petroleum accumulation. Scattered bodies of marble that have a composition suitable for a source of lime are present in the primitive area, but larger and more accessible marble deposits are available immediately west of the area.

High Uintas Primitive Area, Utah

The High Uintas Primitive Area of northeast Utah lies astride the crest of the Uinta Mountains, which are carved from a great east-trending anticline that is bordered on the north and south flanks by steeply dipping faults (M. D. Crittenden and others, r1609). Bedrock within the area consists entirely of sedimentary rocks assigned to the Uinta Mountain Group and classed as younger Precambrian in age.

No mining has been done in this primitive area, and economically significant mineral deposits were not found in it. Faults are numerous in the area, but none show any physical or chemical evidence of the passage of mineralizing solutions. The possibility of ore deposits at depth beneath the area is considered unfavorable, because of the geologic environment. Aeromagnetic and gravity studies give no indication of mineralized zones within the primitive area, nor do they indicate any shallow igneous bodies similar to those associated with mineralized deposits in the Park City and Cottonwood mining districts, 30 to 40 miles to the west. Oil is produced from wells north of the area, but the possibility of oil reservoirs beneath Precambrian rocks within the area is extremely unlikely.

WILDLIFE REFUGES

Mineral-appraisal reports on the following wildlife refuges, or parts of the refuges, have been prepared and placed on open file for public inspection: Alaska—Bering Sea, Bogoslof, Forrester Island, Hazy Island, St. Lazaria, Semidi, Simeonof, Tuxedni; Florida—Cedar Keys, Island Bay, Pelican Island, Passage Key; Georgia—Okefenokee; Maine—Moosehorn; Massachusetts—Monomoy; Michigan—Huron Islands, Michigan Islands, Seney; New Jersey—Great Swamp; New Mexico—Bitter Lake, Bosque del Apache; Oklahoma—Wichita Mountains; Oregon—Hart Mountain, Malheur, Oregon Islands, Three Arch Rocks; Utah—Bear River; Washington—Copalis, Flattery Rocks, Quillayute Needles; and Wisconsin—Gravel Island, Green Bay.

MINERAL RESOURCES OF APPALACHIA

The Appalachian region has abundant and diversified mineral resources that are summarized in a report by the U. S. Geological Survey and the U. S. Bureau of Mines.[17] The role of resources in the regional and national economy is discussed for the use of those planning additional mineral-based industries in this region. The relationships of resources to geologic features are given as guides to mineral exploration.

The mineral-resources report was prepared by 67 specialists of the Geological Survey and Bureau of Mines, who describe the geography and physiography of Appalachia and the causes and effects of the lagging economy, and who evaluate the mineral industry. The main part of the report consists of 50 sections devoted to the principal mineral commodities, their history, production, geology, and resources. The economic importance of mineral resources to the welfare of the Appalachian region is emphasized by the 1964 production of mineral commodities, the values of which

[17] U.S. Geological Survey and U.S. Bureau of Mines, in press, Mineral resources of the Appalachian region: U.S. Geol. Survey Prof. Paper 580, 402 p.

totaled about $2,488 million. Of these mineral commodities, bituminous coal was by far the most important, the 1964 output being valued at $1,640 million.

Fuel resources potentially could support a much larger production. Bituminous and anthracite coal resources are well known; they are probably larger than for any other area of comparable size in the world. Petroleum and natural gas require additional geologic study in order to evaluate total resources. Oil-shale resources, considered to be low grade by present standards, are very large and represent a resource for the future. Peat resources are probably large enough to sustain a manyfold increase in production.

Resources of many construction materials are virtually inexhaustible, particularly limestone, dolomite, clay, shale, sand, and gravel, and including marble, sandstone, granite, and limestone for dimension stone.

Resources of nonmetallic and industrial minerals such as high-calcium limestone, high-grade silica, high-grade clay, feldspar, mica, saline minerals, and olivine are large, and these materials are capable of being utilized to a much greater extent than at present. Others, such as asbestos, barite, kyanite, sillimanite, and talc (including soapstone and sericite schist) occur in moderate to large amounts and require additional study.

Zinc is the only metal produced in large amounts, accounting for about one fourth of our national production. Potential resources of zinc are large and new deposits can be expected to be found. Lead production, although small in terms of national consumption, should also increase. Copper production is also small, but the potential for finding large low-grade copper deposits is good, and output of this metal may increase. The potential for discovery of low-grade gold deposits is good. Iron ores are abundant, but most are low grade and are not as amenable to concentration as ores from other regions. Other metals are present in small amounts or occur in low-grade ores.

Much of the Appalachian region has advanced at a slower economic growth rate than the nation as a whole. Historically, most of its mineral raw materials have been shipped from the area for use elsewhere in the manufacture of higher value products. As pointed out in the report, development of more local industries to utilize these raw materials in finished goods would substantially improve the regional economy. The resource base of the Appalachian region is adequate to support expanded development.

TECHNIQUES OF MINERAL EXPLORATION

Geochemical–reconnaissance results

In a geochemical reconnaissance for metals in the Pequop Mountains and Wood Hills, Elko County, Nev., R. L. Erickson and others (r0334) report that the most successful method was analysis of float cobbles and pebbles collected in the major drainage systems. Conventional stream-sediment sampling and analysis failed to reveal any anomalous metal content except in the drainage lines from one mining district.

Geochemical-exploration investigations by E. V. Post and W. L. Lehmbeck in the Big Creek–Yellow Pine area of west-central Idaho demonstrate that copper, lead, and zinc are comparatively uncommon, and that their mobility in the slightly alkaline waters of the region ($pH = 7.5–7.8$) is low. Arsenic appears to be common, and its mobility is relatively high, anomalous amounts having been detected in stream sediment as much as 2½ miles downstream from gold and antimony-mercury deposits.

Accessory minerals in igneous rocks

In an earlier study of the Osgood stock of quartz monzonite in Humboldt County, Nev., G. J. Neuerburg[18] showed that the distribution of accessory sulfides and magnetite was spatially related to the skarn tungsten deposits, which suggested that minor accessory-mineral distribution as a prospecting tool may prove valuable. Additional studies of this area have also shown that the mercury content of magnetite is enhanced near the known ore deposits and the mercury-in-magnetite pattern is similar to that of the other accessory minerals. On the other hand, more recent similar studies by Nuerburg (r2049) of the Caribou stock in Boulder County, Colo., have shown that the mercury content of magnetite is low in contrast to the Osgood stock, and its distribution pattern, like that of the minor accessory minerals, is not related spatially to the ore deposits.

Botanical investigations

A reevaluation of early geobotanical work by H. L. Cannon in the Atlantic City–South Pass gold district, Fremont County, Wyo., indicates that the absorption of gold by aspen may be useful in prospecting covered areas of the district. The uptake of gold by plants and the distribution of possible indicator plants is being investigated further.

[18] G. J. Neuerburg, 1966, Distribution of selected accessory minerals in the Osgood Mountains stock, Humboldt County, Nevada: U.S. Geol. Survey Misc. Geol. Inv. Map I–471.

Some mosses and liverworts are known throughout the world as indicators of metallic enrichment, particularly of copper, in the substrates. One of these moss species, *Mielichhoferia macrocarpa*, was found by H. T. Shacklette on Amchitka Island, Alaska, and this specimen as well as samples of other "copper mosses" from other regions of the United States and Europe and their substrates were analyzed chemically. The analytical data indicate that these plants grow most commonly, or exclusively, on substrates that are enriched in metal. Shacklette (r0657) suggests that knowledge of the occurrence of these mosses can be used in prospecting by tabulating the habitats of museum-held specimens and then examining these localities by conventional prospecting methods. States in which these plants are known to occur are Alaska, Arizona, California, Michigan, Montana, South Dakota, Tennessee, and Utah.

Mineral exploration by in-situ neutron activation

As a result of a feasibility study, two prototype instruments have been built for silver exploration. F. E. Senftle, Perry Sarigianis, John Evans, and P. W. Philbin report that field tests proved that silver could be easily measured down to about 1.5 oz per ton without resorting to specialized techniques, and that as little as 0.05 oz per ton could probably be detected by use of additional equipment. Twently inches is about the maximum depth of penetration with the current equipment, but a more powerful neutron source might permit use to greater depths.

Statistical analysis of drilling data

Two- and three-dimensional models of Mississippi Valley-type solution-collapse ore-bearing structures have been constructed mathematically from selected drilling data by Helmuth Wedow, Jr. Such models, when used in conjunction with a computer-programmed trend-surface analysis of the same data, suggest that the number of drill holes needed to outline favorable ore structures can be reduced considerably.

Analytical procedures useful in geochemical prospecting

A sensitive procedure that will detect as little as 0.05 ppm Pt and Pd in geologic materials has been developed by C. E. Thompson (p. D236–D238). The basis of the method is the catalytic effect of these metals on the reduction of molybdophosphoric acid to molybdenum blue by using formic acid as the reducing agent. The platinum and palladium are dissolved with hydrobromic acid containing free bromine and are separated from most of the rest of the sample by precipitating with stannous chloride, using tellurium as a carrier.

As little as 0.02 ppm Au in geologic materials can be determined by an improved and relatively simple method developed by C. E. Thompson and H. M. Nakagawa. After the gold is dissolved from a 10-g sample by a cold solution of hydrobromic acid and bromine, it is extracted by methyl isobutyl ketone and estimated by atomizing the ketone into an atomic-absorption spectrophotometer. Use of a relatively large sample tends to minimize variations between replicate determinations caused by erratic distribution of gold particles in the sample.

Description of mercury-vapor detector

The description of a simple mercury-vapor detector by W. W. Vaughn (r1014) will be of interest to those people who are investigating the usefulness of mercury as a pathfinder for concealed deposits of base and precious metals. The detector utilizes a large-volume atomic-absorption technique for quantitative determination of mercury vapor thermally released from crushed rock. A noble-metal amalgamative stage, which is temperature controlled, selectively traps the mercury and eliminates low-level contaminants. One part per billion of mercury can be detected in a 1-g sample.

OFFICE OF MINERALS EXPLORATION

The U.S. Geological Survey, through its Office of Minerals Exploration (OME), encourages exploration for certain minerals within the United States, its territories, and possessions. The program provides financial assistance to private industry on a participating basis, and is available to those who would not ordinarily undertake the proposed exploration at their sole expense and who are unable to obtain the necessary finances on reasonable terms from commercial sources. Exploration may be conducted from the surface or underground. Assistance is not available to "grubstake" or finance prospecting expeditions.

An applicant for OME assistance must own, lease, or have an otherwise valid claim to the property he wishes to explore. A reasonable probability must exist for significant discovery of ore on the property. The applicant must show that he has adequate funds to start the proposed work because the Government's share of the costs is paid monthly only after a report for completed work is received. Repayment to the Government is at the rate of 5-percent royalty on production from the property. If there is no production, no repayment is required.

Minerals or mineral products eligible for financial assistance are:

Antimony	Mercury
Asbestos	Mica (strategic)
Bauxite	Molybdenum
Beryllium	Monazite
Bismuth	Nickel
Cadmium	Platinum group metals
Chromite	Quartz crystals (piezoelectric)
Cobalt	Rare earths
Columbium	Rutile
Copper	Selenium
Corundum	Silver
Diamond (industrial)	Sulfur
Fluorspar	Talc (block steatite)
Gold	Tantalum
Graphite (crucible flake)	Tellurium
Iron ore	Thorium
Kyanite (strategic)	Tin
Manganese	Uranium

The Government will contribute 50 percent of the total allowable costs of exploration for all these commodities except silver, for which as much as 75 percent of the allowable costs is paid.

Activity in the OME program during the first 9 months of fiscal year 1967, and from February 1959, when the first application was processed, to April 1, 1967, is as follows:

	July 1, 1966–Apr. 1, 1967	*Feb. 1959–Apr. 1, 1967*	*Total estimated cost of proposed exploration*
Applications received	51	627	$61, 574, 220
Applications denied	15	264	
Applications withdrawn	29	182	
Executed contracts:			
Number of contracts	17	134	
Total value	$1, 067, 660	$8, 723, 524	
Government share	$746, 810	$4, 756, 674	
Government share spent	$359, 235	$2, 232, 123	
Repaid to Government through royalties on production	$3, 146	$150, 939	

Distribution of OME contracts by principal commodities from February 1959 to April 1, 1967, was as follows:

Principal commodity	*Number of contracts*	*Total value of contracts*	*Percentage of total value*
Silver	43	$3, 214, 026	36.8
Gold	38	2, 255, 269	25.9
Mercury	11	726, 380	8.3
Lead-zinc	7	682, 030	7.8
Lead-zinc-copper	11	487, 641	5.6
Molybdenum	3	384, 438	4.4
Copper	7	383, 550	4.4
Iron	3	199, 580	2.3
Beryllium	3	127, 440	1.5
All others (Cobalt, nickel, fluorspar, mica, uranium)	8	263, 170	3.0
Total (14 commodities)	134	$8, 723, 524	100.0

As of April 1, 1967, exploration was in progress on 17 OME contracts in 7 States, 28 contracts in 9 States either were in recess or had been completed and awaited final settlement, and 47 applications for contracts in 14 States were under review.

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 1967, discharge and water-level data for surface waters were collected at about 8,500 stream-gaging stations and about 1,200 lake- and reservoir-level stations. Continuous or periodic measurements of ground-water levels were made in about 25,000 regular network and project observation wells. The quality of surface waters was monitored at about 2,200 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.

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 being 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 the State, local, or Federal agencies listed on page A217. 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 regions (fig. 1), which correspond to the administrative subdivisions of the Water Resources Division.

Geological Survey participation in the International Hydrologic Decade, a 10-year cooperative international effort in scientific hydrology, continued and was expanded in some projects. This participation is discussed in a few of the following sections as well as elsewhere in the volume as appropriate.

ATLANTIC COAST REGION

The Atlantic coast region, although generally characterized by the availability of moderate to large supplies of water, has a number of problems relating to the quantity and chemical quality of available water. Problems of quantity range from temporary excesses during floods to shortages during droughts, as well as problems related to local or areal differences in rocks, vegetation, and climate. Quality problems include those of salt-water encroachment into surface and ground-water reservoirs near many coastal population centers, and the pollution of numerous streams and some ground-water reservoirs by municipal and industrial wastes. In general, the solution of these problems lies in water management, and the investigations of the Geological Survey provide basic data and interpretations for use in such management.

The results of project investigations summarized below illustrate the water problems of the region and some of the approaches used in their solution.

INTERSTATE STUDIES

Some effects of Northeast drought persist

At the approach of the 1967 growing season the seasonal recovery in the Northeast drought area had proceeded much further than at the same time in 1966, according to H. C. Barksdale. Along the western border of the area, in western New York, Pennsylvania, western Maryland, and West Virginia, normal or above normal conditions had generally replaced the subnormal conditions that have persisted for the past few years. Along the coast, however, some effects of the drought still persist. This is particularly true from Maine through Long Island and in eastern Virginia and eastern North Carolina. In these areas both streamflow and ground-water levels were generally below the seasonal normal at the first of April. In the intervening coastal area the picture was mixed, but in numerous key observation wells ground-water levels were still substantially below normal though above last year. In the absence of a rapid recovery in April and early May, this part of the region went into another growing season with a carryover in deficiency of ground-water storage that could have a serious effect on streamflows in late summer and autumn if precipitation should be deficient.

(Also see discussion of drought conditions in section "New Jersey," below.)

Record low flows in Potomac River

Daily flow in the Potomac River near Washington, D.C., reached a new record low of 606 cfs on Septem-

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

ber 9, 1966, according to R. L. Hanson and E. H. Mohler, Jr. The previous low of record was 733 cfs on November 30, 1930. On August 5, 1966, the flow near Washington had dipped to the 1930 record low, but this was caused by temporary diversion of water to storage in a reservoir 80 miles upstream.

In July 1966, the mean monthly flow of the Potomac at Paw Paw, W. Va., reached a record low of 239 cfs, or 70 percent of the previous July low which occurred in 1965. A minimum daily flow of 210 cfs at Paw Paw on July 31 and August 31, 1966, was the second lowest in the 27 years of record.

Ground-water atlas of Appalachia

G. G. Wyrick, working in cooperation with the U.S. Army Corps of Engineers, has compiled a ground-water atlas of the Appalachian region. The atlas will become a part of the publication "Report for the development of water resources in Appalachia" to be compiled by the Corps of Engineers.

The ground-water atlas is divided into two parts. The first part describes the occurrence of ground water and is based upon geologic reports, records of well tables, and records of streamflow. Features favoring ground-water occurrence, such as major fault zones, glaciofluvial deposits, and areas of highly folded rocks, are shown on one sheet. Other sheets show ground-water discharge, based upon low flow in streams, and the average yield of high-capacity wells, based upon well records, for the region. The second part of the atlas indicates the cost of constructing well fields that will yield 1 mgd, the cost of water from such fields, and the optimum development of ground water per square mile for the region.

The atlas will be used by the Corps of Engineers and other Federal agencies in developing plans for water-resource projects designed to stimulate economic growth in the Appalachian region.

NEW ENGLAND

Ground-water reconnaissance of Vermont

A. L. Hodges, Jr., reports that ground-water reconnaissances of three western drainage basins of Vermont have outlined Pleistocene aquifers with considerable ground-water potential. In southwestern Vermont, permeable water-bearing sands and gravels occur along the western edge of the Green Mountains from Bennington northward to the Winooski River, and in the valleys of the Castleton and Hoosic Rivers. The Lake Champlain lowland from Brandon to the Canadian border has low ground-water potential as it is composed of an undulating bedrock surface with a fill of lacustrine silt and clay. The Winooski basin in west-central Vermont has good ground-water potential along most of its upland tributaries, and along parts of the main stem. Where the Winooski River enters the Champlain lowland, however, permeable channels are covered by thick layers of silt and clay.

Water-resource studies in southeast Connecticut

Studies by C. E. Thomas, Jr., M. A. Cervione, and I. G. Grossman indicate that stratified glacial drift in southeastern Connecticut has large potential for development of ground water on the basis of dependable low flow of influent streams and transmissibilities of the deposits. Transmissibilities range from about 12,000 gpd per ft to about 160,000 gpd per ft as determined from well-log data, specific-capacity data, and aquifer-test data.

Most water in the area, upstream from the salt-water interface, is of excellent chemical quality and is suitable for most uses. A few local quality problems stem from naturally occurring iron and manganese in water from the bedrock; ground water has been polluted locally by organic and inorganic wastes, including fly ash which is spread at places for land fill.

Water resources of Naugatuck River valley, Connecticut

At least 75 feet of permeable sand-and-gravel and gravel deposits occur in parts of the Naugatuck River valley below Thomaston, as reported by W. E. Wilson. The history of many wells tapping this aquifer is one of declining yields due to plugging of well screens. The plugging is believed to be principally the result of deposition of minerals from poor-quality water that is induced to flow from the polluted Naugatuck River. Continuous records of specific conductance of the Naugatuck River at Beacon Falls show that on many days during low flow in 1966, maximum specific conductance exceeded 700 μmhos. Specific conductance varied widely, however, often fluctuating 400 μmhos or more during the course of a day, with several peaks and lows, while streamflow remained steady.

Water-resources investigations in southwest Connecticut

R. B. Ryder, M. P. Thomas, and C. E. Thomas, Jr., report that surface-water resources, used primarily for public water supplies, are near maximum development in southwestern Connecticut. The quality of water of many streams in the area is adversely affected, especially during low flows, by domestic and industrial waste effluents. Specific conductances measured at low flows were as high as 1,300 μmhos upstream from the salt-water interface of coastal streams.

Poorly sorted glaciofluvial deposits of sand and gravel yield up to 2,100 gpm of water to efficient individual public-supply wells and have transmissibilities up to 270,000 gpd per ft. Heterogeneity of the deposits presents difficulties in calculating aquifer coefficients from data collected during typical well "acceptance" tests. In some places deeply weathered marble underlying glacial drift yields up to 122 gpm to individual open-hole wells; this ground water is lower in dissolved solids than is ground water in either the unweathered marble or in the overlying glacial drift.

NEW YORK

Effect of surface storage on steamflow in Oswego River basin

Storage and correlation analyses by C. L. O'Donnell confirm the expected regulatory influence of the Finger Lakes and numerous other lakes, ponds, and swamps on streamflow in the Oswego River. Approximately 75 percent of the entire drainage basin is directly tributary to the lakes; the surface areas of the lakes and ponds constitute 6 percent of the basin. This is an unusually large amount of surface storage and is thought to be the primary reason, aside from the influence of man-imposed regulation, for the well-sustained outflow of the Oswego and its main tributaries.

Some thermodynamic aspects of streams in eastern Oswego River basin

Data collected by W. J. Shampine indicate that many of the streams in the eastern Oswego River basin in central New York are more than 10 times saturation with respect to calcite. Diurnal temperature changes and very rapid changes in CO_2 concentration and pH, caused by photosynthesis, should cause calcite to be precipitated. Apparently the rate of precipitation is not sufficient to maintain equilibrium in the rapidly changing conditions found in streams.

Data also indicate that any water in the basin with a specific conductance less than about 600 μmhos will be calcium carbonate-type water. If the specific conductance is greater than about 600 μmhos the water will be a calcium sulfate or sodium chloride-calcium carbonate type. Apparently solution of minerals more soluble than calcite, such as gypsum or halite, is required to raise the ionic strength above 0.01, which corresponds to a specific conductance of about 600 μmhos.

Shallow ground water in Finger Lakes area

Studies in the Finger Lakes area of central New York by L. J. Crain and J. B. Hood, Jr., have shown that the largest quantities of ground water are available from (1) glacial sand and gravel deposits both north and south of the lakes, (2) delta deposits in the lakes, and (3) carbonate bedrock in the northern part of the area. Yields to individual wells from these deposits range from less than 0.01 to more than 1 mgd. The lake deltas represent unique aquifers because of the large ground-water yields (due to infiltration of lake water) with respect to their small volumes. Water pumped from the delta deposits is more economical than water pumped directly from the lakes, because of lower treatment costs.

The quality of ground water in the southern part of the area is generally satisfactory for most uses. However, ground water in the bedrock aquifers of the northern part usually has high concentrations of dissolved solids. Many of the sand and gravel deposits overlying these bedrock aquifers contain water, high in dissolved solids, that has migrated upward from deep and highly mineralized zones.

Artesian aquifer in northeastern New York

Well data and water-quality data collected by W. A. Hobba, Jr., in northeastern New York indicate the presence of an extensive bedrock artesian aquifer adjacent to Lake Champlain. Cambrian sandstone and Ordovician carbonates form the 200-square-mile aquifer. Reported and measured water levels from 40 bedrock wells indicate that recharge is taking place on the eastern slopes of the Adirondack Mountains. Water probably penetrates the sandy till and enters the vertical joints, fractures, and other openings in the Potsdam Sandstone. The water moves through the aquifer along bedding-plane openings and solution cavities. This movement seems to be little affected by faults normal to the direction of flow. Natural discharge may be to Lake Champlain because in some places the piezometric surface is 25 feet above the level of the lake.

Artesian aquifer recharge on Long Island

The Lloyd Sand Member of the Upper Cretaceous Raritan Formation, an artesian aquifer under Long Island, N.Y., has no outcrop. Fresh-water recharge of the unit was believed to be primarily through the overlying confining layer (clay member of the Raritan Formation). Studies by Julian Soren indicate that in Queens County, at the western end of the island, a buried valley below Flushing Meadow (site of the 1964–65 New York World's Fair) contains permeable Pleistocene deposits and cuts through the Raritan Formation to the crystalline bedrock floor of the island's ground-water reservoir, thus providing good hydraulic continuity between the water table and Lloyd beds. Geologic mapping and water-level data indicate that, in the years around 1960, about one-fourth of the 4½ mgd pumpage from the Lloyd in Queens County was being replenished through the buried valley in about 1 square mile of the county's 113-square-mile area. Similar valleys (mostly unmapped) on Long Island's north shore are also probably important recharge areas for the Lloyd Sand Member.

Water resources of Long Island

N. E. McClymonds reports that on the order of 275 cubic miles of sediments underlying Long Island are saturated with fresh, potable water. By conservative estimate this would mean from 10 to 15 cubic miles of recoverable fresh water in storage at the present time.

G. E. Seaburn reports that two recharge basins have been instrumented to measure total storm runoff from well-defined suburban drainage areas on Long Island. Measurements to date indicate that about 15 percent of the total rain on the drainage areas is measured as inflow to the basins.

NEW JERSEY

Drought recovery slow

Precipitation during 1966 over New Jersey was 39.9 inches, some 10 inches more than in 1965 but 5.6 inches less than the average since 1885, according to J. E. McCall. Soil moisture recovered quickly, and there was relatively little crop damage in 1966. Streamflow recovered more slowly, and runoff varied from about 50 percent of normal in northwestern New Jersey to 80 percent in the northeastern and southern parts of the State for the calendar year. Several of the largest reservoirs in New Jersey filled to nearly normal levels by December 31, 1966, but this was due in large measure to emergency restrictions on water use early in the year followed by voluntary water savings in the last half of the year. Also new ground-water and river sources were tapped in the critical northeastern metropolitan area to relieve the draft on the overdrawn surface reservoirs. The ground-water reservoirs lagged most in their recovery; at year's end almost all observation-well water levels in New Jersey were far below normal and nearly a third of them were at record-low levels for that time of year.

Effect of drought on stream quality in New Jersey

P. W. Anderson reports that the effects of drought conditions, which began in September 1961, on the dissolved-solids content of streams in New Jersey have been analyzed by 2-year moving-average techniques.

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Dissolved solids have increased during the last 6 years (1961–66) approximately 85 percent at the most-downstream fresh-water sampling site in the Passaic River basin, and 30 percent in both the Raritan and Delaware River basins. The lower percentage increase in the latter two basins reflects the influence of streamflow augmentation by upstream reservoirs.

Test drilling in Morris and Essex Counties

A test-drilling program was conducted in the winter and spring of 1965–66 at the request of the Office of Emergency Planning for purposes of locating additional sources of ground-water supplies for the drought-disaster area in northeast New Jersey. John Vecchioli and W. D. Nichols report that 4 areas in east-central Morris County and 1 area in northwestern Essex County were tested. Three of the areas in Morris County proved capable of providing an aggregate yield of 7.5 mgd on a sustained basis from wells constructed in sand and gravel deposits.

PENNSYLVANIA

Schuylkill River basin study

Data analysis by J. E. Biesecker, J. B. Lescinsky, and C. R. Wood of the anthracite coal region within the Schuylkill River basin indicates that approximately 98 percent of all solutes discharged from mines is contributed from underground mines while only 2 percent comes from strip mines. Most of the solutes discharged from underground mines are from abandoned workings.

The effects of an extensive sediment-restoration project, completed in 1951, were determined. The data indicate a measured average annual trap efficiency of 93 percent for a system of 3 desilting basins. Before the restoration project, the average annual sediment discharge from the coal-mining region, measured at Berne, Pa., was 1,260,000 tons. The average annual sediment discharge since completion of the restoration project is only 14,000 tons.

Mine-water pool maps for anthracite fields

Maps outlining the coal-bearing structures, the lowest mined beds, and the outlines of water pools in abandoned and flooded mines have been prepared by W. T. Stuart for the four anthracite fields of northeast Pennsylvania. The data are compiled on forty-three 7½-minute topographic quadrangle maps that also show the overflow points from flooded mines where they have been inventoried. Discharge measurements for most sites are available. At some of the sites it has been determined that daily volumes of flow range from 0 to 100 times the average annual flow for small discharges and from 0.25 to 5 times the average annual flow for larger discharges.

Diffusion in Delaware estuary

A mathematical model has been formulated by R. W. Paulson to investigate the value of the diffusion coefficient in the Delaware River estuary between Torresdale, Pa., and Reedy Island, Del. In this reach of the estuary the cross-sectional area changes nearly in a linear fashion. This geometrical fact coupled with a prescribed general form for the diffusion coefficient allows the solution of a one-dimensional steady-state diffusion equation. Conductivity data from five water-quality monitors operated by the U.S. Geological Survey in cooperation with the Philadelphia Water Department are used to calibrate the model with the estuary. Preliminary results from testing the model on a digital computer indicate that the value of the diffusion coefficient ranges from less than 1,000 sq ft per sec at Torresdale (<3 sq mi per day) to nearly 1,600 sq ft per sec at Reedy Island (about 5 sq mi per day).

Hydrogeology of carbonate rocks of Lancaster quadrangle

Among the carbonate rocks of Cambrian and Ordovician age in the Lancaster 15-minute quadrangle in southeastern Pennsylvania, Harold Meisler and A. E. Becher (p. C232–C235) find that the most reliable sources of ground water are the Ledger and Stonehenge Formations. The least reliable sources of ground water are the Conococheague Group and a recently mapped dolomite unit, the Zooks Corner Formation.

Effects of storage-water release on Lehigh River

The release of 11 billion gallons of water from the Francis E. Walter Reservoir between June 20 and 27, 1966, changed the quality of water in the Lehigh River, Pa. E. F. McCarren and W. B. Keighton (p. D262–D266) report that the temperature of impounded water and the concentration of dissolved oxygen decreased with depth. Releases, which were made from the bottom of the reservoir, increased flow in the river, lowered its temperature, increased its capacity for dissolving oxygen, increased turbulence and diffusion, increased its color, lowered its specific conductance, and slightly lowered its pH. Diurnal variations of water temperature of the river were still evident during the release. At the termination of the releases, river-water quality quickly returned to that at normal base runoff.

MARYLAND

Pesticide analysis of water from Rock Creek

H. R. Feltz reports that a low-flow study conducted in late July 1966 along 21 miles of Rock Creek from its headwaters north of Rockville, Md., to its confluence with the Potomac River in the District of Columbia, revealed the presence of two common chlorinated hydrocarbon pesticides. Concentrations of DDT ranging from 10 to 20 ppt were measured at all 13 sampling sites chosen, but higher values were found immediately above the city of Rockville and at the mouth. Lindane was detected in 10 of 13 samples; concentrations were less than 10 ppt in all of the samples.

Sediment load of Northwest Branch, Anacostia River

Intensive urban development in the upper basin of the Northwest Branch of the Anacostia River north of the District of Columbia has produced large sediment loads for the fourth straight year. According to W. J. Davis, the average annual sediment yield has increased from 470 tons per sq mi in 1962 to 2,300 tons per sq mi in 1966. However, an increase of only 100 tons per sq mi was observed between 1965 and 1966.

Quality of water in Georges Creek

Deric O'Bryan reports that chemical analyses of 33 water samples collected from Georges Creek in western Maryland during low-flow conditions indicated generally increasing contamination downstream as follows: Total dissolved-solids content ranged from 180 ppm in the headwaters (Sand Run at Frostburg) to 1,020 ppm near the mouth at Franklin; SO_4, from 0.6 ppm (upstream near Ocean) to 724 ppm; and Fe from 0.6 ppm (Straub Run near Carlos) to 6.1 ppm. In reverse of the Fe trend, $CaCO_3$ ranged from 84 ppm (Frostburg) to 0.0 at Franklin; nitrates from 58 ppm (Ocean) to 1.0 ppm; and phosphates from 17 ppm at Ocean to 0.0.

Test holes in southern Maryland

In a recently begun investigation of water resources in southern Maryland between Chesapeake Bay and the Potomac River, two 1,500-foot-deep test holes were drilled—one at Prince Frederick, Calvert County, and one at Great Mills, St. Marys County. J. M. Weigle reports that the Cretaceous Magothy Formation apparently occurs at a depth of several hundred feet below sea level under most of southern Maryland and is a potential source of water in a large part of the area. A pre-Magothy unit of coarse sand at 1,300 or 1,400 feet below sea level near Great Mills also appears to be a potential source of water.

NORTH CAROLINA

New well field for city of New Bern

As a part of a detailed geologic and ground-water study of Craven County, a new well field for the city of New Bern has been defined. E. O. Floyd reports that wells in this field—which draw their water from the Black Creek Formation and the upper part of the Tuscaloosca Formation of Cretaceous age—have a specific capacity of about 35 gpm per ft of drawdown, and each well is being pumped at a rate of 2 mgd. The water is low in dissolved solids and requires no treatment before use.

Ground water in Pitt County

A detailed investigation of ground water has been completed in Pitt County, N.C., by C. T. Sumsion. This area of 656 square miles is underlain by coastal-plain sediments ranging in age from Cretaceous to Recent. Seven artesian aquifers were defined; their average storage coefficient is 0.0003 and their transmissibility coefficients range from 1,090 to 18,000 gpd per ft. The quality of the artesian water is excellent; there is no contamination or salt-water encroachment. Municipal wells account for 85 percent of ground-water withdrawal; there is no overdraft.

SOUTH CAROLINA

Water-level decline in Leesville area

G. E. Siple reports a continuous trend of water-level decline in wells penetrating the Tertiary sand aquifers of the Leesville area in the southwestern part of the coastal plain over the past year. The rate of decline exceeds that of a corollary decline in cumulative rainfall departures and probably indicates that withdrawal by pumpage during this period has removed water from storage at a rate faster than the aquifer was being recharged. Such a decline is unprecedented in this hydrogeologic environment (Sand Hills), which normally has sufficient moisture to keep ground-water reservoirs full.

GEORGIA

Structural influence on coastal geology and hydrology

Structural-contour maps of the top of the upper Eocene (Ocala Limestone), of the Oligocene, and of a marker bed in the Miocene have been made by D. O. Gregg from gamma-ray logs correlated with paleontological evidence in Glynn County, Ga. These maps show that present-day islands and the Brunswick peninsula were probably formed around structural highs. Marsh, river, and estuary areas correspond generally to structural depressions. A series of normal faults seem to form wedge-shaped horsts and grabens dissecting a small domelike structure on the Brunswick peninsula, where two areas of salt-water contamination have been identified and partly defined. The high-chloride waters seems to be leaking upward from deeper strata through ineffective confining units or along fault planes and into the principal artesian aquifer (limestone). Because the faults may interfere with lateral ground-water movement, the structural geology partly influences the shape of the piezometric surface of the area.

FLORIDA

Low-flow characteristics of Florida streams

Average minimum-flow data have been compiled by R. C. Heath and E. T. Wimberly for 49 long-term stream-gaging stations located uniformly throughout the State. The Florida Water Resources Law defines the average minimum flow as, "the average of the five lowest monthly mean discharges for each month, January through December, occurring during the past twenty years of natural flow", thus resulting in 12 figures of average minimum flow—1 for each month. In general, the average minimum flow converted to cubic feet per second per square mile is between 0.00 (May) and 1.2 (September) in the peninsula, and from 0.02 (December) to 1.5 (April) in the panhandle, except for the Econfina Creek basin.

The average minimum flow for Econfina Creek is between 3.1 (May) and 3.7 (September) cfs per sq mi because springs contribute most of the flow (spring inflow is about two-thirds of the total annual flow).

Salt-water encroachment near Sarasota

In the Sara-Sands area on Siesta Key near Sarasota, B. F. Joyner, Horace Sutcliffe, Jr., and H. N. Flippo have found that corroded well casings in a surface salty zone and wells open to more than one zone were permitting intermixing of water. In open-hole wells that penetrated more than one water-bearing zone, the saline water in the deeper zone invaded the overlying fresh-water zone. Water from the surface salty zone entered the wells through the corroded casings when ground-water levels receded in the dry season. Better constructed, cement-grouted wells open only to the fresh-water producing zone are effectively curbing the intermixing.

Water resources of mid-Gulf area

Studies by R. N. Cherry, J. W. Stewart, and J. A. Mann indicate that the surface- and ground-water systems in the mid-Gulf area in west-central Florida are highly interrelated. Discharge from streams in the area is mostly from ground water. In parts of the area there is a direct relation between lake level and spring discharge. Indications are that pumpage from well fields may be affecting stream discharge in parts of the area. A number of lakes near large well fields appear to be affected by pumping from the Floridan aquifer.

In general, ground-water recharge areas occur where no streams exist and where lake levels fluctuate over a wide range. The waters in the Floridan aquifer in these areas are low in $CaCO_3$ saturation and have the most recent carbon-14 dates.

Ground-water resources of lower Hillsboro Canal area

The urban and rural areas of the cities of Boca Raton, in southeastern Palm Beach County, and Deerfield Beach, in northeastern Broward County, comprise the Lower Hillsboro Canal area. Deerfield Beach is bounded on 2 sides and Boca Raton on 3 sides by canals and waterways which are normally salty.

Studies in the area by H. J. McCoy indicate that the installation of a salinity-control structure in the El Rio Canal at Boca Raton will protect the recently expanded well field from salt-water encroachment. Studies also indicate that adequate amounts of potable ground water are available from the inland portion of the area to meet the future water demands brought about by the mushrooming population.

Availability of shallow ground water in southwestern St. Lucie County

Water for irrigation of a booming citrus industry in inland parts of St. Lucie County, Fla., is derived chiefly from ground-water infiltration into canals of the Central and Southern Florida Flood Control Systems, according to H. W. Bearden. The canals are dual purpose: They remove excess water to prevent flooding during the rainy season, and they furnish irrigation water during the dry season. The problem of supplying irrigation water is becoming more acute because of the expanding citrus areas. Additional water must come from shallow sources because water from the deep artesian Floridan aquifer is becoming increasingly salty.

Water quality in southern Peace River basin

Studies of the temperature and quality of water from the Floridan aquifer in the southern Peace River basin in southwest Florida by N. P. Dion and M. I. Kaufman reveal a northeast-southwest-trending linear zone of relatively high temperature, high calcium-magnesium sulfate water approximately paralleling the Peace River. The southern Peace River is in a discharge area, and the temperature and quality distributions suggest that ground-water circulation and active solution of evaporites are occurring at depth, possibly in the Oldsmar Limestone of early Eocene age, and that waters from this deep zone are ascending along a linear zone (fault?) of relatively large vertical permeability.

Effects of ground-water pumpage in Peace and Alafia River basins

Large-scale industrial and agricultural development in the Peace and Alafia basins, east-southeast of Tampa, Fla., have resulted in a 10-fold increase in ground-water pumpage from the Floridan aquifer during the period 1934–65, according to M. I. Kaufman. Industrial water use in Polk County, center of a large phosphate industrial complex, was estimated at 360 mgd in 1962. A pumpage increase of 2.3 times the 1962 pumpage is predicted by 1980. Since 1934 the increasing withdrawal of ground water has resulted in artesian water-level declines of more than 50 feet in the area of concentrated pumpage. Associated hydrologic effects within the basins appear to include lowered lake levels and increased sinkhole occurrence.

Monitor test well at Jacksonville

G. W. Leve, D. A. Goolsby, and Warren Anderson report that a monitor test well was drilled to a depth of 2,487 feet at Jacksonville, Fla. The purpose of the well, which was drilled by the reverse-airlift rotary method, was to explore the deeper parts of the Floridan aquifer. A prolific water-producing zone was discovered between 1,900 to 2,050 feet below land-surface datum at the base of the Eocene and the top of the Paleocene rocks. This is the deepest fresh-water producing zone yet found in the aquifer and the deepest penetration of the aquifer by a water test well.

Salt water was penetrated in the aquifer below 2,100 feet in relatively impermeable rocks. Packers were installed in the well to isolate the deeper fresh- and salt-water zones and to monitor them for changes in artesian pressure and salinity.

Silver Springs ground-water basin

Preliminary results of detailed piezometric mapping of the Floridan aquifer in the area of Silver Springs in north-central Florida by G. L. Faulkner indicate an elongate north-northwest-trending ground-water drainage basin covering an area of approximately 1,000 square miles. Silver Springs, the largest springs in the United States from the standpoint of mean discharge, are located in the south-central part of the basin and constitute the one major point of natural ground-water discharge in the basin.

Two large piezometric highs have long been known to be present in the Floridan aquifer of peninsular Florida, one to the north of and one to the south of Silver Springs. The Silver Springs ground-water basin appears to extend well up the southwest flank of the northern high; consequently, the area of the high probably makes an important contribution to the total discharge of the springs. On the other hand, the area of the southern high probably is not a major contributor to the springs.

Initial estimates of mean annual recharge of the Floridan aquifer in the basin area compare favorably with the mean annual discharge of Silver Springs.

PUERTO RICO AND VIRGIN ISLANDS

Water resources of Juana Díaz area, Puerto Rico

The project area of 100 square miles in south-central Puerto Rico is drained by 3 rivers which have formed a 20-square-mile coalesced alluvial fan. E. V. Giusti has found that approximately 35,000 acre-feet of water was pumped by wells during 1966 from the alluvial fan, which by conservative estimate could have yielded 13,000 acre-feet more. Static water levels generally recovered during the wet season. Where water levels had been lowered most, river flow recharged alluvium. Geochemical and geomorphic evidence points to ground-water inflow through the divide from the river adjoining the project area on the west. Quality of water data indicate some sea-water intrusion in an area near the coast and the unsuitability of the Juana Díaz Formation (Oligocene) as a source of ground water. Sediment discharge from the hills and mountains is of the order of 5,000 tons per yr per sq mi of area.

Deep water-exploration well in Puerto Rico

An 800-foot test well was drilled to obtain data on chemical quality and water yield in the Tertiary limestones near Quebradillas in northwestern Puerto Rico. The well, which is one of the deepest ever drilled for water in Puerto Rico, is at an altitude of 421 feet above sea level. D. G. Jordan reports that the aquifer has a slight artesian head. The first water was struck at a depth of 380 feet. The static water level was 352 feet below land surface, and the fluctuation has been less than 1 foot since water was first obtained. Water quality has been very uniform, showing little variation with depth. The water is of the calcium-magnesium bicarbonate type with a dissolved-solids content of about 230 ppm, hardness of 220 ppm, chlorides of 14 ppm, and no iron. On the basis of a preliminary bailing test, the well will yield an estimated 150 gpm. Many solution zones were penetrated throughout the depth of the well, but most of them were filled with residual clay.

Dye-tracer study in karst area, Puerto Rico

In a study using a 20-percent solution of rhodamine-WT dye, R. B. Anders has found that subsurface flow in karst limestone topography in Puerto Rico apparently follows well-established channels. In 2 tests, the average velocity of flow was about 2.6 fpm over straight-line distances of 1.5 and 2.5 miles between dye-injection points in sinkholes and points of entry into Río Tanamá to the northwest. Actual average rates of ground-water movement through the limestone doubtless were faster, for it is unlikely that the routes traveled were straight. The dye tests also indicated that some water traveled eastward through the limestone from the lower reaches of Río Tanamá to a spring on the west side of Río Grande de Arecibo, upstream from the confluence of the two rivers.

Sea-water intrusion in lower Tallaboa Valley, Puerto Rico

By comparison of the chemical characteristics of the ground water in observation wells with those of sea water and with others of particular importance in water utilization, J. R. Díaz has been able to delineate the areal distribution of saline zones and the depth of the fresh–saline water interface in the lower Tallaboa Valley.

The interface ranges from less than 10 feet below mean sea level at a distance of 2,000 feet from the shoreline, to more than 120 feet at a distance of 6,000 feet. The ratio of water level above mean sea level to depth of fresh water in this area is approximately 1 to 4 under pumping conditions in 1966. That is, for each foot of height above mean sea level, 4 feet of fresh water is below mean sea level.

A zone of active sea-water intrusion has been detected in the southwestern section of the valley, in an area of depressed water levels and saline water, caused by overpumping wells near 2 sea-water canals that extend 2,000 feet inland.

Ground water found in Virgin Islands

In test drilling for the Virgin Islands Government and the National Park Service, O. J. Cosner and D. G. Jordan have located limited but significant ground-water supplies on the islands of St. Thomas and St. John in indurated, fractured rocks of volcanic and sedimentary origin. Previous to these investigations, the rocks generally were thought to be barren of ground water.

Rigid control of pumpage is necessary to prevent depletion of the aquifers or salt-water encroachment into them. By careful pumpage, however, safe yields of 500,000 to 3,000,000 gallons a year have been obtained from test wells converted to production wells.

The fractured-rock aquifers do not meet the assumed geologic and hydrologic conditions necessary for obtaining aquifer constants by the familiar constant-rate pumping test. O. J. Cosner and L. G. Moore found that constant-head pumping tests give more realistic results in making estimates of safe yield from wells.

MIDCONTINENT REGION

Water supplies are generally adequate to plentiful in the States of the midcontinent region, and in most years sufficient water has been available for most needs. Accelerating water use for municipal, industrial, and agricultural purposes, plus increasing incidence of overdevelopment and of water-quality deterioration have, however, affected the adequacy of an increasing number of water supplies. These problems, together with the naturally irregular distribution of the water resources in time and space, have determined the emphasis on water-resources investigations in the midcontinent region in 1967.

Appraisals of existing water supplies continue as fundamental to hydrologic information on which to base water development, management, and conservation decisions. In 1967 such investigations revealed abundant reserves of ground water in shallow aquifers in the Mississippi Embayment region, new sources of water for irrigation in Minnesota, and an abundant supply for municipal and industrial growth in Kalamazoo, Mich. Water-deficient areas, such as Decatur County, Iowa, have also been identified in order that planning may incorporate alternatives for water supply to meet anticipated needs. Water-rich areas also are confronted by an increasing array of water-supply problems; for example the city of New Orleans, in planning for urban growth and industrial expansion, sought new sources of water to augment existing supplies from the Mississippi River. Studies by the Geological Survey revealed major aquifers under Lake Pontchartrain capable of providing much of the city's anticipated needs, as well as significant supplies from the Tangipahoa and West Pearl Rivers.

Water development and management decisions increasingly demand thorough knowledge of relationships between streams and lakes and ground-water aquifers. Appraisal and problem-oriented studies in the midcontinent region, therefore, emphasize these relationships in terms of natural and artificial recharge conditions, as in the Twin Cities area, Minnesota, and of base-flow characteristics of streams as related to problems of water supply and waste dilution.

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

INTERSTATE STUDIES

Shallow ground-water resources in Mississippi Embayment

Water in the alluvial and terrace deposits of Quaternary age in the Mississippi and Red River valleys is virtually an undeveloped resource in an area of about 45,000 square miles in the Mississippi Embayment.

According to E. H. Boswell, E. M. Cushing, and R. L. Hosman the Mississippi River valley alluvial aquifer averages slightly more than 100 feet in thickness in an area of 40,000 square miles. Wells yielding 500 gpm or more are common over 90 percent of the area, and yields of more than 5,000 gpm have been reported. Water levels are generally within 20 feet of land surface. The water is generally hard, contains excessive iron, has a low constant temperature, and may be used for some purposes without treatment.

The amount of water stored in the Quaternary deposits is slightly more than 120 trillion gallons. Withdrawals in 1965 averaged about 1,430 mgd or 1,600,000 acre-feet. About 85 percent of this amount was seasonal pumpage for irrigation. Water-level declines of 20 to 30 feet are usual in areas of large withdrawal; however, water levels in many areas generally recover to near normal each year.

Upper Mississippi River basin sediment yield

C. R. Collier reports that analysis by areas in the upper Mississippi River basin indicates that the average annual sediment yields varies inversely with the size of the drainage area; the average curves fit the equation $Y=K/A^{0.12}$, where Y is the annual yield, K is the average yield for 1 square mile of drainage area, and A is the drainage area in square miles. Average annual sediment yields for a 100-square mile drainage area range from about 9 tons per sq mi in the extreme northern part of the basin to about 6,000 tons per sq mi in the bluffs areas in the southern part of the basin.

MINNESOTA

Potential irrigation-water supplies

In a study of two late Wisconsin outwash plains in west-central Minnesota, W. A. Van Voast has located areas where potentially good water supplies for irrigation exist. The two outwash aquifers underlie more than 350 square miles of farmland, presently of low crop production. Transmissibilities as high as 10^5 gpm per ft and storage coefficients of 0.1 or less were found. Preliminary chemical data are also favorable. Supplies should be sufficient for irrigation in most of the two areas if proper well spacings are used. The Crow Wing River drainage basin, central Minnesota, is about 40 percent covered by glacial sand and gravel underlying present and former drainageways. The deposits are very permeable, and specific capacities of wells are as much as 50 gpm per ft of drawdown. Although water quality is suitable for most purposes, locally some pollution has occurred. Studies by E. L. Oakes and D. W. Ericson indicate that the Crow Wing Basin is potentially a major irrigation center in terms of available water supplies.

Analog model of Twin Cities area

The model is a 2-layer system of the Prairie du Chien–Jordan and the Mount Simon–Hinckley aquifer zones, plus surface-water features and interconnections between the streams and aquifers. The model, according to H. O. Reeder, has proved to be a valuable tool in developing new concepts of the hydrology of the area.

In the Prairie du Chien–Jordan zone, water levels have declined 70 feet and 90 feet in the centers of pumping in downtown St. Paul and Minneapolis, respectively, from 1885, before significant pumpage was started, to 1965. The Mississippi and Minnesota Rivers have a significant effect in reducing water-level declines due to pumping. Pumpage has increased from zero in 1885 to about 110 mgd in 1965. About half the water pumped from the Prairie du Chien–Jordan zone is from storage, almost half from the rivers, and a small amount from the lakes. Recharge to the areas of greater water pumpage is both by lateral and downward movement.

In the Mount Simon–Hinckley zone, water levels have declined more than 220 feet in Minneapolis from 1885 to 1965. Pumpage has increased from zero in 1885 to about 35 mgd in 1965. Recharge, although small, probably is primarily by lateral movement through the formation, but a very small amount is by downward movement of water from the Jordan Sandstone (Upper Cambrian). The effect of the rivers on the Mount Simon–Hinckley zone can be demonstrated inasmuch as the head differential between the Jordan and Hinckley aquifers is greater because of the presence of the rivers than it is if the rivers are omitted from the electric analog system (model).

Computer applications for hydrologic data

To facilitate the review of the water-quality program, L. H. Ropes has designed and programed a new type of semilog equivalents per million–parts per million graph for computer application. The program will sort by aquifer, date(s), or discharge, and will plot up to 16 variables selected from a list of 44. Besides the graphic output, the values of the high, low, mean, and standard deviations, as well as the variance of each constituent group, are listed. A program for an associated third-dimension plot of quality versus time or location is also being written.

WISCONSIN

Hydrologic relationships in Fox River basin

Studies of ground-water–surface-water relationships in the Fox River basin, in southeastern Wisconsin, by R. D. Hutchinson show that several lakes, having up to 3½ square miles in area, receive ground water along one side and recharge ground-water supplies on other sides. Subsurface drainage into nearby streams and ground-water pumpage appear to be the main causes of loss from the lakes.

Discharge measurements made in September 1965 by F. C. Dreher and K. S. Brigham at 35 sites show that streamflow in the 942-square-mile Fox (Illinois) River basin was between 0.0 and 0.16 cfs per sq mi of drainage area, after a 3-week period of little or no precipitation. These low flows are equaled or exceeded about 80 percent of the time. Preliminary interpretation indicates that zero flow may be experienced nearly 50 percent of the time in streams draining areas of glacial till, whereas higher dry-weather flow characterizes streams draining glacial deposits of sand and gravel.

Water conserved by cranberry growers

Cranberry growers west of Wisconsin Rapids, Wis., conserved significant amounts of water in 1966 by sprinkling instead of flooding bogs for frost protection, according to a wetlands-hydrology study by L. J. Hamilton. However, the growers had to divert 50 percent more water than average into the wetlands, nearly 800 million cubic feet, to replace evaporation losses because precipitation and runoff into the wetlands was lower than average in 1966. Water supplies in many places can be increased by wells yielding at least 500 gpm from outwash and lake-deposit sands, and from sandstone.

MICHIGAN

Water temperatures in Michigan rivers

A preliminary study of cold-water streams in Michigan by G. E. Hendrickson and C. J. Doonan indicates that water temperatures are closely related to geologic and topographic features of the watershed. Rivers draining areas of permeable sand and gravel are generally cooler in summer than those in areas of silt and clay. Headwaters of streams rising on steep slopes are likely to be cooler in summer than those originating on less steep slopes. Other factors that influence local water temperatures are width and depth of stream and amount of shade.

Recovery of ground-water levels in Pontiac area

In a current water-resources investigation in Oakland County, Mich., F. R. Twenter has found that ground-water levels have risen rapidly in the Pontiac area since 1963. Nearly all ground-water pumpage in that area was stopped in August 1963 when water became available from the city of Detroit. Within 5 months water levels rose 45 feet and have continued to rise. By the latter part of 1966, the water levels had risen a total of 85 feet and were 45 to 50 feet below land surface. As other areas in Oakland County are supplied by water from Detroit, the water levels in those areas may rise also.

Abundant water supply in Kalamazoo County

J. B. Miller and W. B. Allen report that large supplies of ground water can be obtained from the glacial sand and gravel deposits in Kalamazoo County. Little or no ground water is available in the bedrock formations. The areas of greatest potential are in the alluvial deposits of the Kalamazoo River. Yields greater than 1,000 gpm are obtained by induced infiltration from the river. An artesian aquifer which underlies a large part of the county has been extensively developed for industrial and municipal use. Wells in this aquifer yield more than 500 gpm.

Crooked and Eagle Lakes in southwestern Kalamazoo County have risen significantly, primarily because water is being pumped into these lakes from a deep aquifer. This pumping has apparently had little or no effect on nearby lakes in the immediate area.

OHIO

Pumpage and recharge in Mill Creek valley

An electric-analog model study by R. E. Fidler of a 12-mile reach of the Mill Creek valley near Cincinnati shows that the natural recharge to the glacial-outwash aquifer is about 8.5 mgd. Present ground-water pumpage in this industrialized area is 8 to 10 mgd, and future pumpage requirements have been estimated at 25 mgd by the year 2000. Analog-model tests for increasing the ground-water supply show that an injection-well method for artificially recharging the aquifer would be practical. By use of the model, an unlimited number of combinations can be made to determine the location and yields of injection wells that would provide the most effective artificial recharge system.

Mahoning River water supply and pollution

The Mahoning River from Leavittsburg, Ohio, to the Ohio-Pennsylvania state line, is the principal source of cooling water along this highly industrialized and populous reach of river. G. A. Bednar, C. R. Collier, and W. P. Cross report that increases in water temperature, sulfate concentration, and sulfate load correlate with the steel production in the Youngstown district. Disposal of industrial and municipal wastes into the river causes a marked decrease in pH and alkalinity, and a doubling of sulfate concentration between Leavittsburg and the state line. During summer months, water temperatures in the reach often exceed 100°F, and downstream from Youngstown the water temperature is equal to or in excess of 90° for 25 percent of the time.

Water quality of Auglaize River

To define the water quality of the Auglaize River, a tributary to the Maumee River, in northwestern Ohio, intensive sampling was done during June, July, and August 1966. A 45-mile downstream reach of the river including the Ottawa and Blanchard Rivers, two main tributaries, was sampled. According to P. G. Drake, the Blanchard and Ottawa Rivers contribute 40 percent and 27 percent, respectively, of the total dissolved-solids load in the Auglaize River, and are the major sources of contamination.

INDIANA

Sediment yields in Indiana

In a study of 13 drainage basins in Indiana, R. F. Flint reports sediment yields ranging from 20.5 to 1,860 tons per sq mi per yr. These yield figures, computed from short-term sediment records, were adjusted for a 20-year period 1946–65.

Hydrologic relationships in Wabash River basin

Reconnaissance studies of subbasins of the Wabash River basin indicate considerable variation in groundwater contribution to streamflow. This variation is noteworthy in adjacent basins having similar geologic settings, as well as those widely separated in distance and geology. According to D. J. Nyman and R. A. Pettijohn, controlling factors or conditions appear to be (1) the volume of permeable materials which constitute the major aquifers, especially the permeability of terraces and alluvium adjacent to the streams, (2) the physiography (topography) of the basin and the permeability of surface materials as they affect infiltration rates, (3) the variations in vegetation (evapotranspiration), and (4) the intersection of glacially filled valleys by modern drainage.

IOWA

Ground water in Decatur County

J. W. Cagle, Jr., reports that large supplies of ground water are not to be expected from the unconsolidated deposits in Decatur County, Iowa. Locally, however, small-to-moderate supplies are available from these deposits. Large supplies are available from the bedrock at a depth of about 2,600 feet, but this water contains about 2,000 to 2,500 ppm total dissolved solids.

MISSOURI

Storage requirements for Missouri streams

A study of within-year storage requirements by John Skelton indicates that reservoir losses vary within and among physiographic regions in Missouri.

The evaporation loss which is most appropriate to determine within-year storage is that loss during the critical period (4–7 months) corresponding to the selected recurrence interval.

Annual sediment losses can be estimated on the basis of statewide sedimentation surveys and converted to total capacity loss by selection of appropriate time periods. Sediment-deposition rates are generally higher in the plains area than in the plateaus.

Seepage rates may be critical in the Ozark foothills, the flat uplands of the Springfield Plateau, and in many areas of the Salem Plateau. They are insignificant in the Osage Plains and moderate to low in the glacial Till Plains, St. Francois Mountains, and Mississippi and Missouri River hills.

Ground water in Missouri River valley

Recent test drilling indicates that the alluvium underlying the Missouri River flood plain between Jefferson City and St. Charles is as much as 120 feet thick in places, with thicknesses of 80 to 100 feet being most common. The depth to the water table ranges from 15 to 40 feet, but generally is 20 to 25 feet below land surface. Lithologic character of the saturated alluvium suggests that it may be possible to obtain as much as 2,000 gpm from properly constructed wells.

L. F. Emmett and H. G. Jeffrey report that water in alluvial deposits in the Missouri River valley is a hard calcium bicarbonate or calcium–magnesium bicarbonate type, and generally contains more than 1.0 ppm of iron.

The high hardness and iron content are undesirable for domestic or municipal use, and softening and iron removal would be beneficial. For irrigation uses the waters are classed as having a low-alkali hazard and a medium- to high-salinity hazard.

Water quality in Joplin area

H. G. Jeffrey and G. L. Feder report that runoff from areas in southwestern Missouri covered by tailings from zinc-ore processing carries as much as 70 ppm Zn in solution. Ground water in mines, which are overlain by tailings piles, contains as much as 35 ppm Zn, a part of which is derived from rainwater percolating through the tailings piles and into the mines.

Although runoff from the tailings piles contains large amounts of zinc, the volume of water in the receiving stream is sufficient to dilute the runoff from tailings to a zinc content ranging from 1.0 to 1.5 ppm. Despite the fact that many of these tailings piles are more than 50 years old, they still contribute large amounts of zinc to surface and ground waters. It is believed that a small percentage of zinc sulfide left in the tailings after milling is slowly oxidized to the soluble sulfate, which is then leached by water draining the tailings piles.

Summary of water resources in Missouri

Current knowledge of the water resources of Missouri has been summarized in a report[19] prepared by the Geological Survey in collaboration with the Missouri Division of Geological Survey and Water Resources, U.S. Army Corps of Engineers, U.S. Department of Agriculture (Soil Conservation Service), and other Federal and State agencies. The discussion covers existing and proposed water-resource developments; ground-water resources, including springs and caves; surface water in the principal river basins; lakes and reservoirs; quality-of-water conditions; and water use and related problems.

KENTUCKY

Sediment yield in Beaver Creek basin

Although coal mining stopped in 1959 in the Beaver Creek basin area, central Kentucky, an analysis of sediment loads during storm runoff indicates that no reduction in sediment yields has occurred. C. R. Collier reports that during the 1965 water year, 1,200 tons of sediment was discharged from Cane Branch. This sediment load is equivalent to an annual rate of 25,000 tons per sq mi from the strip-mining spoil-bank areas in the watershed.

Ground water from sands in Jackson Purchase region

Geologic and hydrologic studies in the Jackson Purchase region at the northern end of the Mississippi Embayment by R. W. Davis, T. W. Lambert, and A. J. Hansen, Jr., have shown that the westernmost part of the region has a complex distribution of clays and sands in the uppermost Eocene strata. In some areas, wells obtain water from sand below the clay beds. Some of the clays are thought by these workers to grade eastward into sands of the Claiborne Formation. The upper part of the clays probably is a northward extension of the Jackson Formation.

[19] U.S. Geological Survey and Missouri Division of Geological Survey and Water Resources, in press, Mineral and water resources of Missouri: U.S. Cong., 90th, 1st sess., Senate Doc. 19, 399 p., illus., tables. [Published Aug. 1967]

Although some wells tap shallow sand for industrial and public supply, deeper wells in all the western part of the Jackson Purchase can obtain large supplies of water by penetrating below the clay beds to tap sands in the 300- to 400-foot-thick sand section in the lower part of the Claiborne Formation.

Water supply for Mammoth Cave National Park

A cavernous zone near the base of the Haney Limestone Member of the Golconda Formation (Upper Mississippian) is a potential source of ground-water supply in the Mammoth Cave area. Small springs having dry-weather flows usually in excess of 5 gpm issue at numerous places where the cavernous zone crops out along valley sides. In a recent ground reconnaissance, J. A. McCabe and R. V. Cushman successfully used detailed geologic maps to predict the location of springs capable of furnishing adequate supplies for proposed picnic and campground sites in Mammoth Cave National Park. At each proposed site, potential spring horizons were selected in advance of the reconnaissance at map locations where the base of the Haney Limestone Member crossed the center line of small stream valleys. Potential water sources were then easily located, eliminating many miles of traverse in field reconnaissance.

Base flow in Tradewater River basin

A current hydrologic study of the Tradewater River basin in the Western coal field by H. F. Grubb and P. D. Ryder shows that base flows in streams that drain coal-producing areas are generally maintained during periods when the streams in nonmined subbasins have no flow. Large volumes of water, stored in spoil banks, strip pits, and abandoned underground mines, are released during periods of low flow.

ARKANSAS

Water use increases 35 percent

H. N. Halberg and J. W. Stephens have found that use of water in Arkansas during 1965 averaged 2,142 mgd, 35 percent more than in 1960. More than half the 1965 total was for irrigation, of which 80 percent was ground water. The greatest increases since 1960 were use of water for irrigation (from 928 to 1,160 mgd), fish- and bait-raising establishments (from 48 to 179 mgd) and fuel-powered electric plants (from 268 to 423 mgd). Surface water is commonly used in the northwestern half of the State; ground water is commonly used in the southeastern half, or coastal plain, where the alluvium of Quaternary age provides most of the water used for irrigation, and the Sparta Sand, of Tertiary age, provides much of the water used by industry.

TENNESSEE

Unusual geohydrologic features in Great Smoky Mountains National Park

A combination of several unusual geologic and hydrologic features was discovered in drilling a test well for water supply at the Cades Cove Campground in the Great Smoky Mountains National Park, reports W. M. McMaster. The well in the outcrop area of the Precambrian Metcalf Phyllite begins in alluvium of the floor of a nearby small stream, where the ground surface is about 5 feet higher than the stream bed. On the basis of data for other wells in the area, it was expected that the well would penetrate 10 to 20 feet of alluvium and have a shallow water level. Also, according to a recently prepared structure-contour map drawn on the Great Smoky fault, the Metcalf Phyllite was believed to be underlain by the Ordovician Jonesboro Limestone at a depth of less than 100 feet. Instead, the well penetrated 45 feet of alluvial material, 65 feet of clay residuum overlying phyllite, and at a depth of 350 feet had not reached the thrust fault. Rather than the expected shallow water level, the depth to water at the time of the completion of the well was 190 feet.

ALABAMA

Base flow related to geology

L. B. Peirce has studied about 400 unregulated gaged streams in Alabama and delineated general areal relations between geology and dry-weather stream flow. Reflecting the State's diversified geology, median 7-day low flows in Alabama range from no flow in some streams of the Prairie Belt and the Cumberland Plateau to more than 0.5 cfs per sq mi for some streams in the southern coastal plain and a few streams in limestone terranes north of the Tennessee River. When plotted on a map, median 7-day low flows display broad regional consistencies that conform closely with many geologic and physiographic features. These defined hydrologic regions are useful as a basis for appraising, in general, the low-flow characteristics of ungaged streams in each region. However, they are not a dependable basis for quantitative estimates of low flow in a specifiic stream because some individual watersheds display a markedly different dry-weather flow than that generally expected for the region.

MISSISSIPPI

Water supply of Pearl River basin

J. W. Lang reports that of the 26 million acre-feet of average annual rainfall in the 8,760-square mile watershed of the Pearl River basin, about 9 million acre-feet becomes runoff (both ground water and streamflow). A reservoir on the main stream of Pearl River above Jackson, Miss., has a gross volume of 310,000 acre-feet. At least 1 artesian aquifer and 1 water-table aquifer are present nearly everywhere. In the lower reach of the basin as many as 10 aquifers commonly occur between the land surface and the base of the fresh water.

The magnitude of the water supply without man-made storage is indicated by the overflow of the ground water into the streams. The overflow totals about 2,500 cfs (5,000 acre-feet per day) during base-flow periods. Much of the overflow comes from the shallow sand and gravel deposits that mantle the uplands of the south-central part of the basin; they store large amounts of rainfall in wet seasons and then slowly release the water to streams in dry seasons. Yields to streamflow of more than 0.20 cfs per sq mi of drainage area are characteristic of the sandy terrane in this part of the basin, whereas yields of less than 0.05 cfs per sq mi of drainage area are characteristic of the clay, marl, and finer sand terranes of the northern part of the basin.

Aquifers in shallow Quaternary deposits can provide at least 1 mgd of cool (68°–70°F) water at many places and several deeper aquifers (some untapped) of early Quaternary, Pliocene, and Miocene ages are sources of warmer, soft (0–40 ppm hardness) water. In the southern part of the river basin, wells in some of the deeper aquifers flow as much as 3,000 gpm and produce as much as 5,000 gpm by pumping.

Aquifer discovered at Wiggins

A significant aquifer was recently discovered at Wiggins in southeastern Mississippi. T. N. Shows has concluded, on the basis of an aquifer test and electric log of a new municipal well, that large quantities of water can be obtained from deep wells (900–1,000 ft) in the vicinity of Wiggins. A pumping test indicates a transmissibility of a least 300,000 gpd per ft; the specific capacity of the new well is 100 gpm per ft of drawdown.

The water from the new well is of good quality and no treatment is required. Other municipal wells at Wiggins are completed in 200- and 400-foot sands and the water from them requires treatment.

LOUISIANA

New water sources found in New Orleans area

Studies by G. T. Cardwell, M. J. Forbes, Jr., and M. W. Gaydos disclose that large quantities of water of excellent chemical quality are available from artesian aquifers underlying brackish Lake Pontchartrain and from the Tangipahoa and West Pearl Rivers north of the lake. Although shallow aquifers contain fresh water beneath the entire lake, aquifers of intermediate depth (1,000–2,000 ft) contain fresh water only near the north shore; some deep aquifers (2,000–3,000 ft) contain fresh water beneath the northern half of the lake and all deep aquifers contain fresh water beneath the northern one-third. Near the north shore of the lake, 7 to 11 major aquifers having an aggregate thickness of 700 to 1,400 feet contain fresh water to depths of about 3,000 feet. It is estimated that aquifers can yield 1,000 to 5,000 gpm to individual wells and that 14,000 to 27,000 gpm can be developed from the fresh-water section at the sites of 3 test holes near the north shore without undue risk of salt-water encroachment.

Most of the fresh-water flow of the complex lower Pearl River system is carried by the West Pearl River. The development potential, without storage, of the Pearl and Tangipahoa Rivers is indicated by the minimum flows of 1,100 cfs and 264 cfs, respectively. As both streams are tidal in the lower reaches, the amount of water that can be withdrawn without salty water intruding to the diversion site is dependent on the distance upstream to the diversion site. However, natural channel barriers have a limiting effect on the upstream movement of salty water in both streams.

Fresh water in Iberville Parish

C. D. Whiteman, Jr., reports that large quantities of fresh water are available from a system of aquifers in the Plaquemine–White Castle area of Iberville Parish. The aquifer system consists of a thick section of alluvial and deltaic sand and gravel overlain by silt and clay which underlies the modern flood plain of the Mississippi River. Clay beds within the aquifer system are comparatively thin, and none extend across the entire area. The Mississippi River cuts into the top of the aquifer and recharges it in places. Pumpage now averages about 10 mgd and has no significant effect on water levels. Seasonal pumpage of more than 8 mgd from a well field near the river has little effect on water levels less than a mile away, indicating that much higher pumping rates are practical. Yields of more than 1,000 gpm are common from large-diameter wells in the area, and yields of more than 5,500 gpm have been obtained. Salt-water encroachment should not be a serious problem in most of the area suitable for heavy industrial development.

Most of the water is very hard and high in iron, but large quantities of moderately hard water with less than 2 ppm iron can be obtained near White Castle, and small quantities of soft water with less than 0.3 ppm iron can be obtained in the northeastern corner of the area.

ROCKY MOUNTAIN REGION

The scope of geohydrologic investigation in the 12 States of the Rocky Mountain region is nearly as varied as the topography and the climate, yet similarities in investigative methods and results are common. The water of streams is monitored for changes in chemical quality in much the same way in Texas as in South Dakota, and aquifers are being discovered both in the wet mountain valleys of Montana and in the deserts of central Arizona.

Old problems, especially those involving water management and optimum use of water, cannot be completely solved either by accumulation or by application of scientific knowledge—as long as economic conflicts and pressures remain unresolved, or as long as water law and its enforcement are preferential, archaic, or scientifically invalid. Ground-water levels in some areas of highly priced crops continue to decline, to an alarming degree in places. The pumping of irrigation wells may reduce yields of domestic and stock wells, and conflicts arise among water managers, users of ground water, and users of surface water.

Other old problems are being solved by new methods, by old methods, and by combinations of the two. Aquifer coefficients are being determined by their relation to overburden pressure on artesian aquifers. Drainage problems are being solved by the traditional method of installing properly placed interceptor drains and by lowering the water table so that applied water can transport salts below the root zone. Elsewhere, sophisticated electric-analog models are being constructed and calibrated according to data collected in the field by routine methods.

Studies in progress in most of the States in the region are discussed in the following section.

MONTANA

Aquifers of Kalispell Valley

Several newly recognized aquifers have been broadly defined in the Kalispell Valley in northwestern Montana. A recent study by R. L. Konizeski and Alex Brietkrietz has shown that dune sand overlying glacial drift may absorb as much as 0.05 acre-foot of water per acre per day during the spring snowmelt and that this water is discharged by numerous wells and springs. Relatively well sorted beds of glacial drift are recharged locally by pothole lakes and furnish dependable artesian water supplies to many farms. Alluvium along the Flathead River has a transmissibility of more than 1,000,000 gpd per ft and is capable of furnishing large water supplies for irrigation or industrial use. The area's ground-water supplies are largely undeveloped.

Aquifer constants related to overburden pressure

Known values of permeability and storage coefficients were correlated with overburden pressure on an artesian aquifer in the northern part of the Powder River basin, southeastern Montana, by O. J. Taylor. The relation thus established was used to determine permeability and storage coefficients in other parts of the basin.

Drainage problems of Big Horn Canal unit

The Big Horn Canal irrigation unit, southeastern Montana, includes an irrigated terrace and a flood plain. A study by W. B. Hopkins indicates that water applied to the terrace is primarily responsible for waterlogging of the adjacent flood plain, as the water leaving the terrace cannot be transmitted, at the low gradient extent, through the alluvium underlying the flood plain. Swampy areas are thus formed. Evapotranspiration from these areas causes "alkali" soil. Interceptor drains that penetrate the gravel at the landward edge of the flood plain will alleviate part of the waterlogging. Also, lowering the ground-water level several feet below the flood plain will permit applied water to transport salts from "alkali" soil below the root zone.

NORTH DAKOTA

Possible source of sodium sulfate ground water

J. L. Hatchett reports that crystals, tentatively identified as mirabilite, were recovered while test drilling in glacial drift that fills the northwest-southeast trending buried bedrock valley about 8 miles northwest of Stanley, in the northwestern part of the State. The crystals were in an 18-foot section of black clay, which has a total thickness of 92 feet. The clay is overlain by 118 feet of till and is underlain by 111 feet of till.

The presence of these crystals suggests that drainage was restricted and that lakes were formed between glacial advances. Water evaporated and mirabilite crystallized from lakes that were saturated with sodium sulfate. Similar lakes occupy closed basins on the present erosional surface in North Dakota.

Mirabilite and other evaporites that were buried between glacial advances may be the source of some of the sodium sulfate water common in North Dakota.

Flowing wells in bedrock aquifers

M. G. Croft reports that about 75 flowing wells have recently been drilled into the Fox Hills Sandstone (Cretaceous) and the Cannonball Member (Paleocene) of the Fort Union Formation in Mercer and Oliver Counties, west-central North Dakota. One analysis of water from the Fox Hills Sandstone indicated it to be of the sodium bicarbonate type and to contain about 270 ppm chloride and 1.3 ppm iron. Several analyses of water from the Cannonball Member indicate it to be of the sodium bicarbonate type and to contain about 60 ppm chloride and 2 ppm iron.

Drift aquifers and Dakota Sandstone, Traill County

The Cretaceous Dakota Sandstone and sand and gravel deposits in glacial drift are the main sources of ground water in Traill County, east-central North Dakota. The Dakota is thickest in the western two-thirds of the county and thins eastward against a Precambrian bedrock high. Artesian water in the Dakota is highly mineralized and is not suitable for municipal use, according to H. M. Jensen.

Water in the sand and gravel is suitable for most uses; however, where the drift aquifers are hydraulically connected to the Dakota Sandstone, the quality of water in the sand and gravel is poor. East of the bedrock high, water in drift aquifers is of better quality. Here the Dakota is discontinuous and does not readily contribute water to drift aquifers.

Deep aquifers in southwestern North Dakota

According to Henry Trapp, Jr., potable water is available from aquifers as deep as 1,800 feet (probably Fox Hills Sandstone) in Stark County. A well was recently constructed to this depth about 8 miles east of Dickinson. In adjoining Mercer County, wells tapping the Fox Hills Sandstone at depths of 1,800 feet are reported to flow.

Most of Stark County and adjacent Hettinger County are unglaciated, and sandstone and lignite beds of Late Cretaceous and Tertiary age are the principal aquifers.

Continuity of outwash aquifers

Test drilling and well-inventory data in Eddy, Foster, and Wells Counties indicate to Henry Trapp, Jr. that the Rosefield and Carrington aquifers are continuous near the Foster-Wells County line, east-central North Dakota.

The Rosefield aquifer consists of gravel outwash that, in the main, underlies the valley of Rocky Run Creek in Rosefield Township, Eddy County. Most recharge to the Rosefield aquifer evidently originates in Wells County, where a branch of the aquifer underlies a tributary of the James River. There, surficial outwash in the tributary truncates the older buried outwash of the aquifer. The piezometric surface locally is more than 5 feet above the land surface in Rocky Run valley. The water level in the adjoining part of the Carrington aquifer is at a similar elevation but is below the land surface. Old wells in the Rosefield aquifer have continued to flow despite increased withdrawal from the Carrington aquifer for irrigation and public supply.

Seven major aquifers in Grand Forks County

Seven major equifers in Grand Forks County are capable of yielding more than 250 gpm of water to wells, according to T. E. Kelly. Two, the Inkster and Elk Valley aquifers, yield water having an average dissolved-solids content of less than 1,000 ppm. Parts of the Elk Valley aquifer are capable of yields exceeding 500 gpm. This aquifer has more potential for development than any other in the county. The towns of Larimore and Northwood obtain water from the Elk Valley aquifer. The Dakota Sandstone, the most extensive aquifer, underlies all but the southeastern part of the county and is tapped by numerous flowing wells yielding highly mineralized water.

Irrigation possibility in Wells County

F. J. Buturla, Jr., states that test drilling has defined a large aquifer in the glacial deposits in the western part of Wells County, central North Dakota. The aquifer occupies a deep north-south-trending buried valley that underlies the James River.

Preliminary estimates indicate that the ground-water storage in that aquifer is more than 500,000 acre-feet. Analyses indicate that the water ranges from the calcium bicarbonate to the sodium bicarbonate type and that dissolved solids are generally less than 1,000 ppm. Sodium-absorption-ratio ranges from 1 to 4, indicating water suitable for irrigation.

WYOMING

Ground water on Wind River Indian Reservation

Test drilling and hydrologic studies by L. J. McGreevy on the Wind River Indian Reservation, west-central Wyoming, indicate that stock-water supplies are available in areas previously untested for ground water. Much of the reservation is leased for grazing, and stock water has been scarce in some areas. The Wind River Formation of Tertiary age is the principal aquifer. Studies also indicate that enough water is available from alluvium of the Wind River and Little Wind River valleys to supplement surface-water irrigation. In some years, the late-summer surface flow has not been adequate for irrigation. The development of ground water for irrigation also could help alleviate drainage problems in some areas. Wells of moderately high yields can be developed in Mill Creek valley, an area of drainage problems, but the quality of the water for irrigation is questionable.

Ground water in Green River basin

Reconnaissance in the Green River basin of southwestern Wyoming by G. E. Welder has helped determine the extent of a sandstone aquifer in the Tipton Shale Member of the Green River Formation (Eocene). Water in this artesian aquifer is a nuisance to trona mining operations in the south-central part of the basin. A stratigraphic interval consisting chiefly of fine-grained sandstone, but also containing siltstone, marlstone, and limestone, can be traced in the subsurface by means of electric logs over an area of about 4,000 square miles. The aggregate thickness of the sandstone north of T. 22 N. ranges from 200 to 400 feet, but the sandstone thins southward and disappears along a southwestward-trending line about 2 miles south of the town of Green River. The aquifer dips basinward from its outcrops on the east, north, and west and is 1,800 feet below the surface in T. 19 N., R. 110 W. Wells tapping the aquifer near Farson, in the east-central part of the basin, flow at 10 to 170 gpm. The water ranges from 500 to 1,200 ppm in dissolved solids and is suitable for domestic use. In the deeper part of the basin dissolved solids exceed 1,500 ppm. In much of the basin permeability is low, and the aquifer will not yield large quantities of water to wells.

SOUTH DAKOTA

Water-quality monitoring

According to D. G. Adolphson, water from 24 artesian observation wells in southeastern South Dakota has been reanalyzed for chemical quality after an interval of 5 years. Results of the analysis show only slight variations in chemical quality with time. Eventually, water from all 175 observation wells in the State will be analyzed at 5-year intervals to monitor water quality.

Well interference in Sanborn and Miner Counties

Reported interference between irrigation wells and flowing stock and domestic wells in Sanborn and Miner Counties, southeastern South Dakota, was verified in a study by L. W. Howells. All the affected wells tap a buried glacial-drift aquifer. Two irrigation wells, when pumped at 800 to 1,000 gpm each, lowered the piezometric surface by as much as 5 feet, and caused a cessation of flow in stock wells as much as 3 miles away. Although the aquifer underlies more than 200 square miles in the counties and has about 1¼ million acre-feet of water in storage, both the extent of the aquifer in Miner County and the size of the recharge area are much less than originally believed. The aquifer is apparently recharged along narrow flood plains and channels of intermittent streams in northern Miner and southern Kingsbury Counties.

Deep artesian wells on Rosebud Reservation

Artesian wells 1,500 to 3,000 feet deep have become a major source of water in the northern part of the Rosebud Indian Reservation, south-central South Dakota. All the wells being used have been drilled since 1955. Three artesian aquifers are tapped—sandstone beds in the Upper and Lower Cretaceous Dakota Sandstone, sandstone beds in the Lower Cretaceous Inyan Kara Group, and sandy limestone beds in the Ordovician Red River Formation. More than a million gallons of water per day is withdrawn from the aquifers. The head has declined 5 to 10 feet since 1963. Water quality is poor; dissolved solids generally range from 1,400 to 2,000 ppm. Several wells, however, yield water that contains more than 3,000 ppm dissolved solids, according to findings of M. J. Ellis and D. G. Adolphson.

Large outwash aquifer between Sioux Falls and Brookings

According to M. J. Ellis and D. G. Adolphson, water in glacial outwash in the Big Sioux River drainage basin between Sioux Falls and Brookings is not fully developed. In 1964, the outwash held about 200,000 acre-feet of water in transient storage. The average annual amount of ground water used in the basin is estimated to be about 14,500 acre-feet; summarized as follows, in acre-feet: Public water supplies, 11,000; irrigation, 1,500; livestock, 1,500; and rural domestic use, 500. Water from the outwash is very hard but otherwise is of good quality; most of it is suitable for irrigation and industrial use. Approximately 95 percent of the recharge water that enters the basin each year evaporates or transpires.

Filling of Oahe Reservoir recharges aquifer

Filling of the Oahe Reservoir has resulted in a 20-foot rise in water level in a buried-valley aquifer in the area of Pollock, north-central South Dakota, during the period 1962-66. Studies by N. C. Koch indicate that the aquifer ranges in depth from 200 to 400 feet and underlies about 150 square miles of Campbell County. The channel gradient is eastward, whereas the hydraulic gradient is probably westward toward the Missouri River.

Irrigation from Niobrara Formation possible in Bon Homme County

The Upper Cretaceous Niobrara Formation of chalk, marl, and shale is distributed widely in South Dakota. The formation is nearly always water bearing, and, in eastern South Dakota, it is commonly used as a source of domestic and stock water. The aquifer generally is artesian, but in places it is under water-table conditions. Well yields are generally less than 10 gpm, but yields in excess of 650 gpm have been reported in areas where the chalk is well fractured and jointed. The quality of the water is normally similar to that in neighboring sand and gravel aquifers. Studies by D. G. Jorgensen indicate that in Bon Homme County, southeastern South Dakota, the Niobrara is commonly well fractured; thus, the aquifer may yield water in quantities adequate for irrigation.

NEBRASKA

Availability and use of water in Nebraska

A statewide water-use inventory by F. B. Shaffer shows that Nebraska has an abundant supply of water of good quality. Surface flow entering the State in 1964 (a near-normal year) totaled 1,500,000 acre-feet, and the amount leaving was 6,860,000 acre-feet. The measured use of water from both surface and underground sources was 13 bgd. The greatest use, 8 bgd, was for generation of electric power. Irrigation, 3.5 bgd, was the next largest use. Other uses were for fuel-powered electric plants and for municipal, rural domestic and livestock, and industrial water supplies.

UTAH

Ground-water quality stable in most of Utah

Observed fluctuations of water levels since 1957 do not seem to be accompanied by significant changes in water quality. However, in the Sevier Desert, Pavant Valley, and the Beryl-Enterprise area of southern Utah, increases in dissolved solids have been observed in some wells. A. H. Handy reports that in the Pavant Valley and the Beryl-Enterprise area the increases are probably partly due to recirculation of water applied to irrigated fields.

Springs in upper Fremont Valley

About 90 cfs of water discharges from springs and flowing wells in the upper Fremont River valley, south-central Utah, an area of about 50 square miles. This conclusion was reached by L. J. Bjorklund from an inventory of springs and wells and a gain and loss study of the Fremont River through the valley. Most of the water discharges from or near Tertiary volcanic rocks, which dip gently toward and skirt the valley on the west and on the south. The 2 largest springs, measured at 17.5 and 16 cfs, discharge directly from the volcanic rocks, but many smaller springs discharge from both the volcanic rocks and from alluvium in wet meadows on the valley floor near the rocks. The springs are probably recharged on volcanic highlands 10 to 30 miles to the southwest and south in the Parker Mountain–Aquarius Plateau area, where annual precipitation is as much as 25 inches. Annual precipitation in the upper Fremont valley is only about 7 inches.

Chemicals added to soil affect ground-water quality

Dissolved-solids content and relative percentages of chemical constituents in water from two public-supply wells in southern Skull Valley, northwestern Utah, have fluctuated during 1951–65, according to K. M. Waddell. The relative percentages of calcium, sulfate, and nitrate in the water have increased with increasing dissolved-solids content. Considerable amounts of calcium, ammonium, and iron sulfate have been applied to irrigated lawns near the wells. The fluctuation in chemical quality of the water is attributed to recirculation of irrigation water to the aquifer during periods of extended pumping.

Recharge in Salt Lake County

Infiltration from stream channels that cross the alluvial bench at the base of the Wasatch Range has long been considered a major source of ground-water recharge in the Jordan Valley near Salt Lake City. According to A. G. Hely and others, streamflow data during the past 3 years indicate that infiltration losses across the bench are much less than was supposed prior to the comprehensive study of Salt Lake County, and are negligible in some areas. These data suggest that the recharge mechanism involves flow through sedimentary rocks in the adjacent Wasatch Range.

Desert basins of western Utah under study

Sixteen intermontane basins in western Utah have a low population density, generally are undeveloped, and have not recently been studied hydrologically. A basin-by-basin reconnaissance series was begun in 1964. Despite wide variations in geology and physiography, preliminary evaluation indicates that hydrologic aspects of most of the basins may be similar. Precipitation is the major, if not the only, source of water. Streamflow and ground-water recharge are significant only if peripheral mountains are large in area and are above an altitude of 6,000 feet. Most precipitation evaporates or transpires. Hood and Rush[20] estimated that of about 2 million acre-feet of annual precipitation in Snake Valley, Utah and Nevada, only about 25,000 acre-feet leaves the valley, mainly as ground-water outflow through valley fill and possibly through carbonate rocks. Similar studies in Skull Valley, Tooele County, indicate that only 1 to 2 percent of annual precipitation leaves as streamflow and ground-water outflow to Great Salt Lake. R. D. Feltis has shown that only about 4 to 8 percent of precipitation in Cedar Valley, Utah County, leaves, mainly as ground-water outflow, through or around consolidated rocks at the east edge of the valley. Rush Valley, Tooele County, a topographically closed basin, may have some eastward outflow, but nearly all the 500,000 acre-feet of annual precipitation seems to be consumed within the valley.

[20] J. W. Hood, and F. E. Rush, 1965, Water-resources appraisal of the Snake Valley area, Utah and Nevada: Utah State Engineer Tech. Pub. 14; *also* Nevada Dept. Conserv. and Nat. Resources, Water Resources—Reconn. Ser. Rept. 34, 40 p.

Artesian conditions in Sanpete Valley

Sanpete Valley, an intermontane valley of about 250 square miles in central Utah, is bounded on the east by the Wasatch Plateau and on the west by the Gunnison Plateau. Along the flank of the Wasatch Plateau, sedimentary rocks dip steeply westward toward and beneath the valley. The crest of the plateau is at an altitude of more than 10,000 feet and receives 30 to 40 inches of precipitation annually. According to G. B. Robinson, Jr., much of this water seeps into the westward-dipping rocks through cracks, joints, and bedding planes that have been enlarged by solution, and moves under the valley. Observed collapsed structures and sinkholes confirm water intake in the plateau, and oil and gas exploratory holes and coal prospect holes on the flanks of the plateau have encountered warm water under high head. Apparently westward water movement is blocked by the upfaulted Gunnison Plateau. As a result, artesian conditions generally prevail throughout the valley.

COLORADO

Hydrology of South Platte River valley

According to D. R. Albin, ground-water levels and seepage gains and losses indicate that irrigation pumpage in the South Platte River valley below Denver can be increased without mining ground water. The measurements, made in November 1966, indicate that all ground water removed from storage during the irrigation season will be replaced before spring 1967. However, increased consumptive use of water from wells will decrease return flow to the river, and many junior appropriators depend upon return flow for diversions.

Molybdenum content of Colorado stream water

According to P. T. Voegeli, Sr., and R. U. King, the molybdenum content of Colorado stream water is greatest in streams associated with deposits of the metal and (or) areas where the ore is processed—thus indicating that chemical analysis of stream water may be a valuable exploration tool. At present, analyses indicate that the molybdenum content is greatest in upper reaches of Eagle River and Tenmile Creek, west-central Colorado.

Calibration of Arkansas Valley analog model progresses

J. E. Moore and C. T. Jenkins report that the installation of additional electrical components has eliminated most of the problems in calibrating the analog model of the Arkansas Valley. With these refinements, the model can be verified. It can now be used to predict results of changes in water management. For example, a quantitative evaluation of the effect of pumpage on stream depletion was made. This evaluation was a criterion used by the State Engineer to administer wells in the valley in 1966.

Oil-shale hydrology, Piceance Creek basin

Geohydrologic studies by D. L. Coffin, F. A. Welder, and R. K. Glanzman indicate that most ground water in the Piceance Creek basin, northwestern Colorado, is in the oil-shale-bearing Parachute Creek Member of the Green River Formation (Eocene). Water enters on the edge of the basin, moves downdip under artesian conditions, and discharges as springs or into stream alluvium. The water is generally of the sodium bicarbonate type, and dissolved-solids content ranges from 400 to 25,000 ppm. The higher concentrations are in the northern part of the basin. Pumping tests show that the Parachute Creek Member may yield as much as 1,000 gpm to wells, but that large drawdowns will occur over a wide area. The occurrence of water in the fractured oil shale will be a factor in recovery of oil in most of the basin, regardless of mining methods.

Multiaquifer wells in southeastern Colorado

L. A. Hershey and D. B. Richards state that withdrawal of ground water for irrigation in southeastern Colorado has resulted in water-level declines of as much as 120 feet since 1946. The number of irrigation wells has increased from 13 in 1950 to more than 600 in 1966. Most wells tap more than one of five aquifers. Wells and test holes have cross-connected aquifers having different heads. In places, water is draining from the water-table aquifer and is locally recharging artesian aquifers. In other places, water from artesian aquifers applied to cropland recharges the water-table aquifer.

KANSAS

Dissolved-solids content little changed by return flow

Return flow from irrigation that began in 1963 has had little noticeable effect on the composition of the dissolved-solids load in the Smoky Hill River in the vicinity of Hays, according to R. B. Leonard. Percentages of the major ions in seepage water and inflow from individual tributaries differed, but streamflow in the 22-mile reach of the river south of, and adjacent to, the Cedar Bluff Irrigation District varied only slightly from water of the calcium sulfate type impounded in the reservoir. Seepage and tributary inflow from the downstream (eastern) part of the district contained higher percentages of chloride, lower percentages of sulfate, and more nitrate than those from nonirrigated drainage areas in the district, but the relatively slight differences may not be directly attributable to return flow from irrigation.

Electric-analog studies continue

Application of electric-analog techniques to groundwater studies in Kansas continues to aid the understanding of areal hydrology. The analog model helps determine the adequacy of field data in delineating effects of various hydrologic factors. Development of electric-analog models is continuing for analysis of areas in western Kansas, where withdrawal of ground water for irrigation exceeds natural recharge, according to J. D. Winslow.

Ground-water development in northwestern Kansas

Restudy of ground-water development in 6 counties of northwestern Kansas by E. D. Jenkins, R. H. Pearl, and R. S. Roberts indicates that the number of large-capacity wells increased from 70 to 1,050 in the past 20 years. Well discharge exceeds recharge, so that water is being mined in parts of the area. Water levels have declined from 5 to 20 feet in places in Sherman County where the number of wells and pumpage are greatest, but declines are only minor in the rest of the area. Aquifers, principally the Tertiary Ogallala Formation, range in thickness from 0 to 200 feet and yield from 100 to 2,000 gpm to wells. Transmissibility commonly ranges from 15,000 to 100,000 gpd per ft.

ARIZONA

Hydrology of Paradise Valley

F. E. Arteaga, N. D. White, M. E. Cooley, and A. F. Sutheimer report that updating and analyzing of basic data pertaining to ground water in Paradise Valley, Maricopa County, included a reconnaissance of subsurface geology which permitted identification of four water-bearing units—the upper, middle, and lower alluvium, and a red unit. Differences in the water-bearing characteristics of the units were determined. Changes in water levels and quality of water were related to pumping.

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Phoenix basin being dewatered

The Phoenix basin is being dewatered by ground-water withdrawal. Between 1923 and 1964, more than 57 million acre-feet of aquifer had been dewatered. The decline in water level has caused ground-water divides to develop along buried peripheral boundaries, thereby reducing underflow into and out of the basin. Statistical analysis of static water levels, pumping levels, and well discharges, and deep-well current-meter tests indicate a large reduction in the water-yielding capacity of the alluvial aquifer with depth. The upper 400 to 500 feet of the aquifer yields roughly 10 times more water per foot of saturated material penetrated than underlying materials to depths as great as 2,500 feet. Where the upper high-yielding part of the aquifer has been dewatered, well yields are drastically reduced, even if wells are greatly deepened.

Ground water being depleted in central Arizona

The ground-water reservoir in central Arizona is being depleted because annual irrigation pumpage of 3.2 million acre-feet greatly exceeds recharge. Water levels in places are declining as much as 20 feet per year. Results of an electric-analog study, by T. W. Anderson, indicate that depth to water in 1984 will range from 50 to 750 feet and that the average decline rate will be about 5 feet per year if the pumping pattern does not change.

Fault forms ground-water barrier

A fault that forms a ground-water barrier has been found near Yuma by F. H. Olmsted and O. J. Loeltz. The position of the fault is indicated by topographic, geophysical, and hydrologic evidence. It extends southeastward from where it crosses the Colorado River, 9 miles downstream from Yuma, to a point on the Sonora boundary, 28 miles east of the Colorado River. The fault seems to be a branch of the San Andreas fault system. About 11 miles south of Yuma, ground-water levels on the northeast side of the fault are more than 30 feet higher than those of the southwest side. The barrier significantly influences the direction and quantity of ground-water movement from the recharge area, which is 25,000 acres of irrigated citrus land. The fault will have an important bearing on any program for large-scale salvage of water from an extensive ground-water mound that has built up under the Yuma Mesa during the past 20 years as a result of irrigation with Colorado River water.

NEW MEXICO

Water-resources investigation in DeBaca County

Reconnaissance geologic mapping of about 2,600 square miles, investigation of subsurface data, and an inventory of about 800 wells have been completed by J. W. Shomaker and W. A. Mourant in connection with a water-resources study of DeBaca County N. Mex. Most ground water in the county occurs in sandstone and shale aquifers of Permian and Triassic age, and discharges to alluvium filling the valley of the Pecos River. With a few notable exceptions, yields from bedrock aquifers are meager, and water quality is poor. A complex relationship exists between the Pecos River and ground water in both valley fill and bedrock.

Water-resources investigation in Harding County

Data collected in initial stages of investigation of the water resources of Harding County, N. Mex., by F. D. Trauger, indicate an erratic and unpredictable occurrence of water in large areas of the county, an almost total absence of economically available water at depths less than 800 feet in large areas, and an anomalous occurrence of supplies of water adequate for irrigation in the Rosebud area (Tps. 18, 19, and 20 N., R. 33 E.).

The absence of water at reasonably shallow depths under large areas results mostly from deep dissection of the surface of the Tertiary Ogallala Formation by the Canadian River and Ute Creek, which serve as base levels toward which ground water moves. The rocks adjacent to the streams are drained to levels near the altitude of the river channels. Small bodies of water perched in the Cretaceous Dakota Sandstone supply most of the stock and domestic wells west of the "cap rock" (Ogallala Formation) west of Roy and south of Mosquero.

The aquifer supplying irrigation water near Rosebud is not yet identified. The main part of the water may be coming from the rocks of Jurassic and Cretaceous age. Irrigation waters in the southeast corner of the county near Logan may be coming from the Triassic Santa Rosa Sandstone.

Ground-water hydrology of Capitan Limestone

The Permian Capitan aquifer extends around the margin of the Delaware Basin in southeastern New Mexico and contains water of moderate to very saline quality. Surrounding formations contain water that is much more saline. This study defines the relationship of the complex Capitan aquifer to the Pecos River and to surrounding formations. W. L. Hiss has obtained data from oil companies on abandoned oil test wells ranging from 12,000 to 18,000 feet in depth. These wells have been plugged back to the base of the Capitan aquifer and completed as observation and test wells. Water levels in the Capitan aquifer in southeastern New Mexico are lowering at approximately 1½ to 2 feet per month whereas water levels near Carlsbad show little or no net decline. The Permian Basin Well Data System magnetic tape file of scout records for over 30,000 oil tests in the project area is being used for basic information and as supporting framework in the machine data-processing facets of this study.

TEXAS

Quality of surface water, Brazos River basin

Jack Rawson computed the dissolved-solids content of surface water from three subdivisions of the Brazos River basin. Water from the upper basin had the highest content. During 1949–64, dissolved solids, chloride, and sulfate, in tons per square mile per year from the 13,310 square miles of contributing area upstream from Possum Kingdom Reservoir, averaged 84, 30, and 19 tons, respectively; in the middle basin (3,620 square miles between Possum Kingdom and Whitney Reservoirs) averaged about 28, 2, and 2 tons; and in the lower basin between Whitney Reservoir and Richmond (17,850 square miles), averaged 53, 6, and 6 tons. Water in the upstream reaches of the Brazos is usually unsuitable for most uses because of high dissolved-solids content. Although quality improves downstream, water in lower reaches is usually unsuitable for domestic and some industrial uses. The water is usually suitable for irrigation of rice (the principal irrigated crop), however, and for supplemental irrigation of other crops. Water in most of the larger tributaries below Possum Kingdom Reservoir is suitable or can be made suitable for most uses.

Quality of surface water, Trinity River basin

In a study of the chemical quality of surface water of the Trinity River basin, D. K. Leifeste and L. S. Hughes found that natural runoff is of good chemical quality, suitable for most uses, but that quality in many places has been degraded by municipal and industrial wastes. The dissolved-solids content is less than 250 ppm in most places, but it is higher in the Elm Fork Trinity River, Richland Creek, Tehuacana Creek, and Menard Creek subbasins, where oil-field brine is reaching the streams. Municipal wastes discharged into the Trinity in the Dallas–Fort Worth area also increase the dissolved-solids content. All reservoirs contain water of good quality. At potential reservoir sites, water is also of good quality except in Richland and Tehuacana Creeks.

Geophysical surveys useful in Hueco bolson

Seismic-refraction and earth-resistivity surveys proved potentially useful in the study of saline-water resources of the Hueco bolson, El Paso. Seismic data, in conjunction with data from a deep test hole, showed a deep trough (probably bounded by a fault on the west) paralleling the Franklin Mountains. Fill in the center of the trough was calculated to be about 9,000 feet thick.

Electric soundings (earth-resistivity) were made only in two small areas. The soundings were excellent for detecting the fresh-water–salt-water interface, as well as for mapping bedrock topography to a maximum depth of about 3,000 feet. M. E. Davis found that the interface roughly corresponds to a line separating water of more than 5,000 ppm from water of less than 5,000 ppm dissolved solids. The sundings also provided useful information on the lithologic character of shallower strata.

PACIFIC COAST REGION

The wide variability in the amount and distribution of water in Alaska, California, Hawaii, Idaho, Nevada, Oregon, and Washington does not identify the full scope of water problems in the Pacific coast region. Some people no longer are content to accept water where and how they find it. They want the water brought to them in the amounts they need when they need it. Further, they expect it to be of good quality and safe for their use.

To help achieve redistribution of water, some of the most ambitious schemes devised for transporting water have involved supplies located in the Pacific coast region. The greater the demand and the more complex the development, the more necessary it is for the water resource to be defined precisely with respect to its availability, distribution, variability, and quality. The increasing demands for water also result in increasing competition for the water by the different user groups. This competition increases still further the urgency for reliable assessments of the total water resource and the potential for reuse.

The Geological Survey began studying water resources of the West almost from its beginning, more than 75 years ago. The extent and intensiveness of its investigations have varied according to the prevailing demands in the different parts of the region. Even now, in some areas, only preliminary investigations are needed to meet local requirements currently and in the near future. For other areas the investigations must be most comprehensive to provide the information needed for wise planning and management. Investigations are conducted also to establish or clarify basic principles needed to further the Survey's capacity to evaluate water resources.

Some elements of investigations, special studies, and research are reported in other sections of this volume, such as in those on marine geology and hydrology, geochemistry of water, hydraulic and hydrologic studies, and glaciology. Results discussed in this section largely were obtained during regular areal investigations of water resources. These studies range in complexity and intensity from initial reconnaissance such as that carried on in Nevada through the comprehensive studies of the Willamette basin in Oregon and those of the Puget Sound and adjacent waters in Washington.

ALASKA

Iron content of ground water near Juneau

A recent study of the Mendenhall Valley by W. W. Barnwell and C. W. Boning[21] points out that ground water obtained from metamorphic bedrock contains less than 1.0 ppm of iron. Iron concentrations in ground water from the glacial sediments abruptly increase from less than 1.0 ppm in sand and gravel along the east side of the valley to 5 or 6 ppm in fine-grained organic sediments in the center of the valley. Other conditions affecting the quality of water in the valley include the presence of glacial flour, or silt, in several streams and the possibility of salt-water encroachment from tidewater in Gastineau Channel in the southern end of the valley.

More ground water available in Homer area

Additional ground-water development in the Tertiary Kenai Formation, particularly in areas north of the Homer escarpment, is considered feasible from studies by R. M. Waller, A. J. Feulner, and D. A. Morris.[22] In the past, yields of 25 to 30 gpm were obtained from wells in the Kenai Formation or Quaternary deposits in the Homer area in southern Alaska. Test drilling north of the escarpment indicates that yields of water of 50 to 80 gpm and of satisfactory chemical quality are available in that area.

Infiltration gallery provides low-chloride water at Ocean Cape

A. J. Feulner, H. H. Heyward, and C. G. Angelo (p. C189–C191) report that an 80-foot infiltration gallery has supplied enough water for a military facility at Ocean Cape in southern Alaska for the past 3½ years. The chloride content seasonally has ranged from 22 to 34 ppm—far less than the maximum of 515 ppm chloride reached in the vertical well which previously supplied the facility. The horizontal gallery is about 4.3 feet above mean sea level and is 250 feet inland from the shoreline.

[21] W. W. Barnwell and C. W. Boning, in press, Water resources and surficial geology of the Mendenhall Valley, Alaska: U.S. Geol Survey Hydrol. Inv. Atlas HA–259.

[22] R. M. Waller, A. J. Feulner, and D. A. Morris, in press, Water resources, Homer area, south-central Alaska: U.S. Geol Survey Hydrol. Inv. Atlas HA–187.

PACIFIC NORTHWEST

The Pacific Northwest, comprising the States of Idaho, Oregon, and Washington, contains extensive mountainous areas with precipitation reaching a high of about 200 inches per year. In each of the 3 States, however, there are also large plains or plateaus with relatively small amounts of precipitation, in places as little as about 8 inches per year.

Hydrology of Willamette basin analyzed

Studies of streamflow in the Willamette basin in western Oregon by E. A. Oster and C. H. Swift III reveal that the average annual runoff contributed to the Columbia River was 3.0 cfs per sq mi by the 11,200-square-mile drainage basin for the 1928–63 reference period. The average annual runoff ranges from about 1.0 cfs per sq mi in the lower lying lands of central and southwestern parts of the basin to more than 7.5 cfs per sq mi in the higher altitudes of the eastern and northeastern parts.

Profiles of stream temperatures for July and August, prepared by A. M. Moore, show that temperatures of Willamette basin streams increase progressively downstream. The temperatures of east-side tributaries, which drain the higher parts of the Cascade Range, increase 10° to 15°F in their 40- to 90-mile lengths. West-side tributaries, which drain the Coast Range, head at lower altitudes where air and water temperatures are higher, and hence the temperature of these streams increases only 3° to 7°F in about 40 miles. The profiles were based on temperature data for water years 1954–62. Minimum summer water temperatures during that period occurred in July 1955 and maximum temperatures in July 1958. Earlier studies by Moore have shown that these temperature extremes were events having a probable recurrence interval of 25 or more years.

R. J. Madison has found that the chemical quality of water in streams in the Willamette basin has not changed significantly since it was first determined in 1912. Although the use of water for irrigation has increased continuously in the last 50 years, increases in salt load from irrigation return flows have been negligible. The dissolved-solids content generally ranges from less than 40 to 85 ppm, and the water is a calcium–magnesium bicarbonate type. The silica content, which generally ranges between 10 and 25 ppm, may limit the use of water by some industries.

The annual sediment discharge of the Willamette River at Portland averages about 2½ million tons, according to R. C. Williams. The annual sediment yield of the basin ranges from about 60 to 470 tons per sq mi—a rather narrow range for an 11,000-square-mile area. Sediment discharge is generally low in the Willamette basin because of a combination of favorable climatic and physiographic factors. The steeper terrain in the basin is an area of resistant rocks, is heavily vegetated, and has the greatest runoff. Lower lying areas receive less precipitation, a large part of which infiltrates into porous alluvial deposits.

Ground-water resources of the Willamette Valley are far from being fully utilized, according to A. R. Leonard. It is estimated that the valley area may receive as much as 1¼ million acre-feet of recharge annually by direct infiltration of precipitation and a large additional amount by underflow and seepage into the alluvial fans of streams debouching from the mountains. Further, ground-water storage in the alluvial deposits is many times the annual replenishment. The largest use of ground water presently is for irrigation of about 75,000 acres.

Hydrology of Puget Sound region evaluated

The Geological Survey is nearing completion of its role as lead agency in a hydrologic study of the Puget Sound region. The region, designated Puget Sound and Adjacent Waters, comprises 13,355 square miles of land and inland water and 2,427 square miles of salt water in western Washington. Donald Richardson reports that the total runoff in the region averaged about 40 million acre-feet per year during 1931–60. The average depth of runoff was 55 inches, but locally ranged from about 10 inches to more than 140 inches. Despite the large annual runoff, storage is needed to alleviate seasonal water shortages in some areas. Floods and drainage problems also occur in some of the larger valleys.

Ground water is available in extensive deposits of glacial drift throughout most of the Puget Sound lowlands. The chemical quality of both surface- and ground-water supplies is generally excellent. The normal range of the dissolved-solids content in the ground water is 85 to 150 ppm. However, large amounts of dissolved solids and iron occur in water from a few isolated wells. Sediment in most streams occurs in large amounts only during periods of intense rain. By contrast, streams of glacial origin are turbid most of the time, and contain large amounts of fine sediment during warm summer months.

Water-yield estimate in Little Lost River basin, Idaho

Earlier reconnaissance estimates of the hydrologic parameters of the Little Lost River basin in Butte County have been confirmed in a restudy by H. A. Waite and S. D. Decker. The total average annual water yield of the basin was found to be 187,000 acre-feet from a study of perimeter inflow adjusted to a 15-year average. This compares with the prior estimate by Mundorff and others[23] of 190,000 acre-feet.

Periodic measurements at 12 surface-water sites were correlated with records of 3 gaging stations. The gage records in turn were correlated with streamflow records in adjacent basins of similar runoff characteristics. From these correlations, values for water years 1961 and 1962 were adjusted to 15-year averages. Altitude-precipitation relationships were used to supplement the streamflow correlations. These correlations provide the basis for computing the water yield.

Water levels decline in Goose Creek–Rock Creek area, southern Idaho

Studies by E. G. Crosthwaite indicate that pumping ground water for irrigation from silicic volcanic rocks has lowered water levels as much as 150 feet during the past 30 years. Pumping from a limestone aquifer in the study area has caused water levels to decline as much as 125 feet in the past 5 years. Water levels have declined from a few feet to a few tens of feet as a result of pumping from wells in basalt and alluvial aquifers in the same area. About 425 irrigation wells currently pump about 180,000 acre-feet a year from the 4 aquifers.

Ground water available in Olympic National Park, Wash.

According to K. L. Walters, test drilling in the alluvium of the major valleys of Olympic National Park in western Washington shows that ground water can supply the needs of public campgrounds and other park facilities. The grain size of the alluvium increases rapidly as the heads of valleys are approached, and at some localities the alluvium consists of a bed of boulders overlain by a few feet of sandy silt. Under such conditions, large-diameter dug wells excavated by hand or power shovel may be the most economical method of developing water supplies. The bedrock of the park has very little ground-water potential.

Water supplies in Coulee Dam National Recreation Area, Wash.

Water supplies have been located and developed from Pleistocene deposits adjacent to Franklin D. Roosevelt Lake in Stevens County from studies by H. W. Anderson, Jr. At Gifford campground, an alluvial fan buried beneath Nespelem Silt of middle Pinedale age was tapped by a test well which had a spe-

[23] M. J. Mundorff, H. C. Broom, and Chabot Kilburn, 1963, Reconnaissance of the hydrology of the Little Lost River basin, Idaho: U.S. Geol. Survey Water-Supply Paper 1539–Q, 51 p.

cific capacity of 25 gpm per ft of drawdown. At Hunters campground, a test well tapped gravel in an abandoned channel of Hunters Creek. The gravel, beneath 135 feet of Nespelem Silt, is underlain by heaving silty sand. Turbidity of the water finally was eliminated by placing a 3-foot-long 2-inch well point near the center of the perforated section of the original 8-inch casing and packing very coarse sand into the annular space between the two.

Faults largely control movement of ground water in basalt in south-central Washington

The regional ground-water reservoir underlying the Goldendale area, Klickitat County, Wash., is a thick, gently folded sequence of permeable basalt flows broken into large rectangular blocks by vertical strike-slip faults. J. E. Luzier finds that the movement of ground water in the basalt is controlled in large part by the faults.

Low-flow loss from South Santiam River, Oreg.

D. C. Helm reports that the South Santiam River loses about 15 percent (about 25 cfs) of its water during low-flow periods as it crosses an alluvial fan near Lebanon, Linn County. No other significant losses or gains occur downstream along the South Santiam nor along the course of the main Santiam River to which it is tributary.

Regional water table lower than lakes in Oregon Cascades

E. R. Hampton reports that a test well was drilled 1,039 feet into the Pliocene and Pleistocene lavas and pyroclastics of the Cascade Range in southern Oregon without reaching the regional water table. The well was drilled at the North entrance of Crater Lake National Park, near the crest of the Cascade Range. The bottom (altitude 4,963 ft) of the well is 220 feet below the level of Diamond Lake only 5 miles to the north, and 1,223 feet below the level of Crater Lake 6 miles to the south.

Structure in Columbia River Group important to occurrence of ground water

Compilation of information on tectonic structures in the basalt of the Columbia River Group (Miocene and Pliocene) shows that the structures are associated with the Pliocene and Pleistocene deformations of the Basin and Range region, Blue Mountains uplift, and Cascade Range, according to R. C. Newcomb (p. B88–B93). The study also shows that ground-water levels are maintained near the land surface in many places by synclinal structures or impermeable barrier faults in the basalt. Likewise, the stream valleys are shown to be generally consequent in relation to the structures of the deformed basalt.

The general lack of vertical permeability across the stratified basalt flows, and the resultant saucerlike containment of surface water in closed synclines, was utilized in the location of the possible pump-storage reservoir adjacent to the Columbia River, south-central Washington, according to L. L. Young.

CALIFORNIA

Ground water studied in National Monuments

Test drilling has shown that small water supplies are available from fractured rhyolitic tuff breccia near faults in the western part of Pinnacles National Monument, San Benito County. J. P. Akers reports that 2 wells drilled in those materials initially flowed at a rate of 15 gpm. One of the wells has supplied a large camping facility with water for more than 6 months with little head loss.

W. R. Hotchkiss finds that sufficient water is available from fractured basalt and other volcanic rocks for development of new visitor and administration complexes in the Lava Beds National Monument, Modoc and Siskiyou Counties. Water is readily available, but generally contains more than 500 ppm dissolved solids in the area adjacent to lacustrine sediments surrounding the city of Tulelake. The quality of water is considerably better at a distance from the lacustrine sediments and in fractured basalt beneath the sediments.

As many as 400 wells and springs are within the Death Valley Monument area, Inyo County, according to initial studies by G. A. Miller. Most of the large springs of good quality are in the Panamint Mountains along the west side of the valley. On the east side of Death Valley many of the springs and seeps in the Black Mountains and Funeral Mountains are small and produce water of poor, but drinkable, quality.

Ground water in older alluvium in western Madera County

H. T. Mitten, R. A. LeBlanc, and G. L. Bertoldi have found that most of the fresh ground water in western Madera County occurs in older alluvium of Quaternary age. This alluvium dips gently southwestward and thickens from 0 feet near the Sierra Nevada foothills to about 1,000 feet near the trough of the San Joaquin Valley. The alluvium is composed of intercalated lenses of sand, silt, and clay. It includes an extensive, nearly horizontal clay bed, the E clay, that underlies the western two-thirds of the area. The clay ranges in thickness from 0 to 70 feet and in depth from about 100 to 400 feet below land surface.

Ground water occurs as an unconfined water body above and east of the E clay, and as a confined water body below the E clay. Water levels for the unconfined water body range in depth from about 20 to 100 feet. The piezometric surface of confined water below the E clay is 50 to 100 feet below land surface. The water generally is a bicarbonate water suitable for agricultural and domestic use, but poorer quality chloride water, some with more than 2,000 ppm dissolved solids, occurs locally east of the San Joaquin River.

Depletion of ground-water storage in Cuyama Valley

W. V. Swarzenski reports that pumping of ground water for irrigation in Cuyama Valley, Santa Barbara County, has resulted in depletion of storage by at least 400,000 acre-feet since 1947. The water table has declined 100 to 150 feet in the heavily pumped eastern part of the valley. Gross pumpage has been about 50,000 acre-feet per year but has exceeded 60,000 acre-feet in some years. It is estimated that the annual overdraft is 20,000 to 25,000 acre-feet.

Calcium-magnesium ratios identify water-producing zones in Purisima Formation

J. J. Hickey reports that the major hydrogeologic unit in the Soquel-Aptos area, Santa Cruz County, is the Purisima Formation of Tertiary age. It can be divided into three subunits, characterized as predominantly silt, sand, and silty sand. The water in the sandy subunit has calcium-magnesium ratios ranging from 2.8 to 3.4, whereas water in the silty sand subunit has ratios ranging from 0.3 to 1.1. Calcium-magnesium ratios have proved very successful in identifying the producing zones in the Purisima.

Geohydrologic data in Mojave River basin

Preliminary studies of geohydrologic data of the Mojave River basin of southeastern California by W. F. Hardt and S. G. Robson indicate that: (1) The river alluvium is generally more permeable than the older alluvium in the valley, (2) recharge to the river alluvium is by infrequent floodflow in the Mojave River, (3) faults that cross the river alinement act as barriers to ground-water movement, and (4) ground-water pumpage from 1931 to spring 1964 has resulted in maximum declines of at least 40 to 50 feet east of Hesperia, adjacent to the Mojave River, and in Hinkley Valley.

Imported water can be stored underground in San Gorgonio Pass area

Hydrologic, geologic, and geophysical data have been utilized by R. M. Bloyd, Jr., to delineate ground-water subunits in the San Gorgonio Pass area, Riverside County. The combined information permits the San Gorgonio Pass Water Agency to make tentative selection of technically feasible sites to store imported water in the ground.

Test wells near Barstow, San Bernardino County

G. A. Miller reports that 2 test wells 750 and 850 feet deep, in a synclinal structure south of the Marine Corps Supply Center, Barstow (Nebo area), revealed that the alluvial-fan material of Pleistocene age would yield only moderate quantities of water to wells. The water in the deeper part of the fan deposits locally contains more than 2,000 ppm dissolved solids, approximately half of which is sulfate.

Relation of runoff to other hydrologic factors

S. E. Rantz (p. D281–D283) has found that in the humid basins of north coastal California, average annual runoff is linearly related to average annual precipitation and potential evapotranspiration. Average annual water loss is virtually independent of average annual precipitation because the great bulk of the annual precipitation and runoff occurs in the winter months when evapotranspiration demands are light.

Bulk precipitation in Mojave Desert

Chemical analyses of 41 samples of bulk precipitation (rain plus dry fallout accumulated in a collector between rains) from 12 places in the Mojave Desert, San Bernardino County, showed that most samples were of a calcium bicarbonate type. However, local accumulations of saline dust probably explain many variations. Specific conductance of the samples ranged from 8.9 to 823 μmhos, with strong inverse correlation with quantities of rain. Bulk precipitation in the Mojave Desert is closely similar chemically to bulk precipitation sampled at Menlo Park, Calif., in 1957–59 despite the totally different geographic environments involved, according to J. H. Feth (p. C222–C227).

Summary of water resources in California

Current knowledge of the water resources of California has been summarized in a report (U.S. Geological Survey, r2111) prepared by the Geological Survey in collaboration with the California Department of Water Resources and the U.S. Bureau of Reclamation. The discussion considers ground-water and surface-water resources, the quality of these waters, and the development and use of water resources and associated problems.

NEVADA

Water supply of Eagle Valley appraised

A study of Eagle Valley in western Nevada by G. F. Worts, Jr., and G. T. Malmberg (r1467) indicates that the water supply is ample to meet the needs of Carson City and the surrounding area for at least the next decade. The estimated average annual supply from surface- and ground-water sources is about 10,000 acre-feet. The development of a ground-water supply from the fine-grained alluvial deposits will require considerable skill in water-well construction. The pumpage of 1,000 acre-feet in 1966, and less in prior years, has caused only minor and localized storage depletion.

Washoe Valley study completed

The water resources of Washoe Valley between Reno and Carson City, Nev., were more than adequate to meet the 1965 needs, which were about 8,000 acre-feet of water. According to a study by F. E. Rush, the system yield has been estimated to range between 15,000 and 25,000 acre-feet per year, depending on how it is operated. Most of the natural discharge is by evaporation from the shallow lakes on the valley floor. The evaporation rate is estimated at 14,000 acre-feet per year.

Effects of pumping in Diamond Valley

J. R. Harrill finds that pumping during the period 1950–65 in Diamond Valley in central Nevada has depleted ground-water storage by an estimated 60,000 acre-feet, roughly the same as the accumulated net pumpage. However, continued pumping in the south end of the valley probably never will salvage all the natural discharge, which is estimated to be 30,000 acre-feet per year. Hence, a local overdraft probably will occur in the area of present (1966) development.

Water-resources reconnaissance completed for 15 valleys

Reconnaissance of water resources has been completed for 15 valleys during the year. Preliminary estimates of the perennial yield, on the basis of estimates of annual recharge to and discharge from the ground-water reservoir for the valleys, are as follows: 10,000 acre-feet for the Nevada segment of Honey Lake Valley, 2,000 acre-feet for Warm Springs Valley, 1,200 acre-feet for Lemmon Valley, 800 acre-feet for Red Rock Valley, 16,000 acre-feet for Smoke Creek Desert, 2,500 acre-feet for San Emidio Desert, 1,100 acre-feet for Painters Flat, and less than 500 acre-feet each for Rawhide Flats, Cold Spring, Dry and Newcomb Lakes, Spanish Springs, Sun and Antelope Valleys, and Bedell Flat. Subsurface inflow through consolidated rocks probably is an important element in the water budgets for Honey Lake Valley and Rawhide Flats. The various estimates are based on studies by T. E. Eakin, D. E. Everett, P. A. Glancy, and F. E. Rush.

In a study of the Walker Lake area, D. E. Everett and F. E. Rush (r2106) estimate that the evaporation losses from Walker Lake average about 100,000 acre-feet per year more than the inflow to the lake.

Structural controls of ground-water movement

Hydrologic, geologic, and water-quality data show that the regional carbonate-aquifer systems in the miogeosynclinal rocks of south-central Nevada—some of which may integrate many intermountain basins—are actually compartmentalized by major structural features, according to I. J. Winograd. Controls on ground-water movement are exerted by major wrench, thrust, and normal faults, and by folds.

Runoff in Nevada portion of Snake River basin

The average annual runoff in the Nevada part of the Snake River basin was computed by D. O. Moore to be about 697,000 acre-feet. An additional 17,000 acre-feet flows into Nevada from Idaho. Of the 714,000 acre-foot total, about 503,000 acre feet flows into Idaho and about 30,000 acre-feet flows into Utah. This runoff is mainly derived from snowmelt in the mountain blocks, and occurs principally during the period March to July.

HAWAII

Recharge minimizes streamflow in Kona area

Annual rainfall in the Kona district, on the southwest slopes of Mauna Loa and Hualalai volcanoes on the island of Hawaii, ranges from 20 inches at the shore to about 100 inches at 2,500 feet above sea level. George Yamanaga, G. T. Hirashima, and D. A. Davis report that streamflow in the Kona area is small even in the rainy zone, probably largely because most of the rainfall soaks in rapidly and moves downward to the water table near sea level where it is discharged at springs and seeps at the shore. The discharge is brackish or saline because of mixing with sea water in the highly permeable aquifer. Effects of mixing extend a considerable distance inland, and in some places the ground water is brackish a mile or more from the sea.

DATA ACQUISITION AND DISSEMINATION

OFFICE OF WATER DATA COORDINATION

The Office of Water Data Coordination was established in the Geological Survey in 1964 to implement Bureau of the Budget Circular A–67, which set forth guidelines for the coordination of Federal water-data activities concerned with streams, lakes, reservoirs, estuaries, and ground water.

Implementation of Circular A–67 involves three main functions—the design and operation of a national water-data network, the coordination of the acquisition of water data, and the assembling of a catalog of information on water data and data acquisition activities. On-going activities relating to these functions were continued throughout the year.

Of particular note was the progress in assembling the Catalog of Information. This catalog consists of a published index listing data-acquisition activities, computerized storage on magnetic tape of details of these activities, and maps showing locations. Parts of the catalog relating to quality of water and surface-water station-type activities of Federal agencies were completed, and the collection and processing of information for ground-water stations and for hydrologic investigations is underway. Work is underway also to obtain similar information from State and other non-Federal agencies so as to make the catalog as comprehensive as possible.

RAPID COLLECTION AND DISSEMINATION OF DATA FOR WATER MANAGEMENT

Research and development of techniques for rapid collection and dissemination of flood information have been broadened to include daily issuance of data on streamflow and water quality in the lower Delaware River basin. It has been found to be feasible to gather data in Trenton, N.J., from eight gaging stations equipped with telemetering devices as of 0800 daily and to transmit current discharge via teletype by 0830 to the U.S. Weather Bureau, the U.S. Army Corps of Engineers, the Delaware River Basin Commission, the Delaware River Master, and both the Philadelphia and Harrisburg offices of the U.S. Geological Survey. The Philadelphia office of the Survey transmits water-quality data on the same teletype network to Trenton and others mentioned, and also retransmits streamflow and water-quality data on a commercial teletype net whose subscribers include television and radio stations, newspapers, the Philadelphia Water Department, electric utilities and other large industries in the Philadelphia area. Weekly transmissions via teletype give current storage in all major reservoirs, forecast salinity conditions in the Delaware Estuary for the next week and forecast daily flow at Trenton for the next week. The last two items required development of special techniques including a digital model. The Weather Bureau transmits daily weather conditions and forecasts on the same teletype systems and issues flood warnings as required. Recently developed automatic-sensing and telemetering equipment has been ordered which, when installed, will increase the number of reportable parameters to 10 and increase the number of reporting river stations in the network to as many as 15. There is no limit to the number of subscribers on the teletype networks.

WATER-TEMPERATURE PROFILES FOR COLUMBIA AND SNAKE RIVERS

An effective method for presentation of water-temperature data has been developed by the Northwest Water Resources Data Center at Portland, Oreg. Maximum and minimum water temperatures for the current week or month for main-stem stations on the Columbia and Snake Rivers are plotted against river miles. Above the profile, the river-mile points of entrance of major tributaries is shown and the maximum and minimum temperatures of those tributaries for the same period are listed. This graphic method of presenting data is far superior to the use of tabular data because the reader can see at a glance how the water temperature changes as the water moves downstream. The effect of reservoir releases, significant thermal loading by industry, and the entrance of tributary flow of significantly different temperature than the main-stem water are dramatically shown by abrupt rises or drops in the main-stem profile.

These profiles do not appear in a formal report or publication but are released in the weekly and monthly reports of the Data Center to those people and agencies who need current data for water-management problems.

WATER-INFORMATION DATA PROCESSING

Over the past decade the digital computer has had a significant impact on the practice and profession of scientific hydrology. For example, it has very substantially reduced the time and drudgery required in some investigations, and perhaps more important is the profound effect it has had, and is continuing to have, on hydrologic and hydrodynamic research. (See section "Computer Technology.")

One of the first tasks undertaken and accomplished in preparation for installation of the new nationwide digital-computing system of the Geological Survey was the conversion of the 127-reel magnetic-tape file of daily streamflow records to industry-compatible magnetic tapes usable with the new system. Because of the greatly increased speed and capacity of the new computing system and because of its nationwide character, new data-processing procedures and systems are being tested and put into use.

W. L. Isherwood and T. R. Dyar have devised several new programs for use in processing a major portion of all stream-discharge data. A series of 14 computer programs written by J. M. McNellis and C. O. Morgan, Lawrence, Kans., are being used as the basis for development of the new ground-water data-processing scheme. M. D. Edwards and T. A. Wilson are continuing to develop the various computing techniques needed for processing quality-of-water data. Most programs have been prepared using the language PL/1, which has been found particularly well suited to the problems of water-information data processing.

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 in them which are leasable under the Mineral Leasing Acts for public, acquired, and Outer Continental Shelf (OCS) lands; and to preservation of public-land reservoir sites to assure their availability, as needed, for future water-resources development. The basic objective of Conservation Division activities is the conservation of natural resources on Federal lands through the application of authorized Federal controls. These controls have the purpose of protecting the public interest by promoting the efficient and timely development, maximum utilization, and proper disposal of those resources.

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 computes, collects, and accounts for royalties to insure that the government receives a fair return for the exploitation of its lands and minerals. Similar functions are performed by the Division for some Indian lands.

Field offices of the Division are listed on page A223. Geologic and hydrologic work in progress by geologists and engineers of the Conservation Division is given in the list of investigations starting on page A229, 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 Geological Survey charged the Director with the responsibility of classifying the public domain lands. In order to prevent alienation of lands containing valuable minerals not subject to the general mining laws, large areas of such lands were withdrawn and classified, and they may not be disposed of without a reservation of mineral rights to the government. Withdrawn lands not yet classified are being systematically investigated geologically and evaluated for their mineral potential.

Mineral-land classification is a determination of the mineral or nonmineral character of the Federal lands in terms of the quality, thickness, depth, and extent of leasable mineral deposits. The geologic data for evaluating these criteria are obtained from all sources, including detailed mapping and sampling. Continual reappraisal of classifications and revision of the standards to be used in classification determinations are required to keep resource evaluations consistent with current geologic knowledge, mineral technology, and land use.

Mineral-land classification complements the leasing provisions of the Mineral Leasing Act by reserving to the government, in cases of disposal of public land, title to such energy resources as coal, oil, gas, oil shale, asphalt, and bituminous sands, and such fertilizer and industrial minerals as phosphate, potash, sodium, and sulfur. All minerals in acquired and Outer Continental Shelf lands are reserved and are subjct to the Mineral Leasing Acts.

Currently about 53 million acres of withdrawn or prospectively valuable mineral lands require classification for leasable minerals to protect the public mineral estate in the event of surface disposal and to provide data for intelligent multiple land-use management. Areas included in lease applications are classified to determine whether they shall be subject to competitive or noncompetitive mineral lease or permit. More than 30,000 lease applications are reported on each year.

Determinations of mineral potential are made for the guidance of various executive agencies, at their request, on specific tracts of Federal lands under their supervision that are proposed for sale or exchange. Nearly 8,000 such reports were made to other Federal agencies in 1967.

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 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 development of hydroelectric power. Today the objective of this program is to identify, evaluate, classify, and segregate from disposal or adverse use, all reservoir sites on the public lands which have a significant potential for future development, thus contributing to the preservation of a scarce and vanishing valuable natural resource. The program includes stream-basin investigations to identify and evaluate reservoir sites, and resource studies to provide land-administering agencies with information basic to land disposal and multiple-use management decisions. It also includes the continuing review of previous classification as more reliable streamflow and topographic data are accumulated, as technology changes, and as alternative river developments are undertaken or completed. 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 1967, about 212,000 acres of land withdrawn for waterpower purposes were reviewed.

The Geological Survey conducts a limited specialized mapping program, largely confined to sites in Alaska, to aid in 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 lake bottoms are contoured by precise sounding surveys.

Grinnell and Sperry Glaciers in Glacier National Park, Mont.; Nisqually Glacier in Mount Rainier 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 MINERAL LEASING

Supervision of exploration, prospecting, development, and recovery of leasable minerals in deposit on Federal lands is a function of the U.S. Geological Survey under delegation from the Secretary of the Interior. It includes: (1) Geologic and engineering investigation of deposits of oil, gas, coal, oil shale, phosphate, potash, sodium, and sulfur under application for lease or prospecting permit; (2) Approval of plans for drilling, mining, and producing these commodities; (3) Inspection of operations to insure compliance with operating regulations, lease terms, and approved plans for development; (4) Performance, or witnessing, of pressure and flow tests on oil and gas wells; (5) Determination of well spacing patterns that will permit optimum production of oil and gas with minimum expenditure of reservoir energy; (6) Verification of production and collection of royalties; and (7) Investigation of unleased Federal lands near producing fields to determine if they contain deposits which are threatened by drainage. In event of 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 Geological Survey acts as an advisor to the Secretary of the Interior, to other bureaus of the Department, and to other Government agencies concerned with 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 1967, are returned directly to the Federal Treasury. Total royalties from all Federal- and Indian-land minerals exceeded $250 million in 1967.

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 1967.

The lead discovery reported in southeast Missouri last year is under extensive development. Three new shafts have been sunk, and 32 miles of railroad and 2 new lead smelters have been built. Most of the developments are on private land, but about half the ultimate production will come from federally owned land.

Mineral production, value, and royalties for fiscal year 1967

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other [2] (tons)	Value (dollars)	Royalty (dollars)
Public	187, 218, 000	818, 329, 000	493, 751, 000	28, 426, 000	850, 916, 000	86, 085, 000
Acquired	10, 477, 000	25, 481, 000	460, 000	193, 000	40, 051, 000	4, 572, 000
Indian	32, 347, 000	128, 408, 000	71, 379, 000	11, 580, 000	130, 390, 000	16, 396, 000
Military	1, 298, 000	46, 826, 000	54, 783, 000	----------	14, 587, 000	2, 422, 000
Outer Continental Shelf	199, 000, 000	1, 100, 000, 000	----------	1, 930, 000	855, 000, 000	145, 000, 000
Naval Petroleum Reserve No. 2	3, 100, 000	5, 000, 000	13, 000, 000	----------	12, 000, 000	1, 500, 000
Total	433, 440, 000	2, 124, 044, 000	633, 373, 000	42, 129, 000	1,902,944,000	255, 975, 000

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

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND PUBLIC HEALTH

Geology and hydrology applied to engineering and public health are important in appraising hazards that affect an expanding population.

The U.S. Geological Survey provided the U.S. Atomic Energy Commission consultation on geologic aspects of the safety of approximately 11 proposed sites for nuclear reactors. Similarly, geologic and hydrologic assessments were made of sites for testing explosive nuclear devices, used both for weapons and for peaceful purposes. During the year, geologic reconnaissance was made of two new test sites proposed to supplement the present Nevada Test Site: one in central Nevada north of the Nevada Test Site, the other on Amchitka Island, Alaska.

In connection with disposal of radioactive wastes, transportation of radionuclides by streams was investigated in the Columbia River below the Hanford, Wash., plant of the AEC, and in the Clinch and Tennessee Rivers. At the National Reactor Testing Station, Idaho, distribution and migration of radioactive wastes that are discharged underground were studied.

As a follow-up on Project BRECCIA of the On-Site Inspection Program for underground nuclear explosions, a revisit to Amchitka confirmed that recognizable damage to tundra vegetation persists for months and probably for years.

Undesirable inorganic and organic waste products and natural constituents in surface and ground waters complicate development of water resources. Topics investigated include acid mine drainage in Kentucky, West Virginia, and Pennsylvania; salt-water contamination in South Carolina, Florida, and Puerto Rico; and industrial- and agricultural-waste contamination in northwestern Oregon, western Tennessee, northeastern New Jersey, Long Island, and Nebraska.

Data acquisition continues in identifying minor elements with relation to geographic distribution of several diseases as reported by the U.S. Public Health Service. Quantities of certain elements in cultivated soils can apparently be used to identify areas of different cardiovascular mortality rates.

Engineering geologic maps on a scale of 1:250,000 were made of the Northeast Corridor, the highly urbanized stretch between Washington and Boston, on behalf of the U.S. Department of Transportation. Other urban studies were continued. A reconnaissance examination was made of selected coal-mine waste piles in parts of Appalachia to appraise their instability.

Studies of land subsidence caused by fluid withdrawl were continued in California, Nevada, Arizona, and Texas.

Outstanding floods took place during the year in the north-central States and in Georgia, Texas, North Dakota, southern California, West Virginia, and Pennsylvania. Studies of flood frequency and flood maps of urban areas were made on a continuing basis.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

VELA ON-SITE INSPECTION PROGRAM

In fiscal year 1966, the Geological Survey directed two field trials for the VELA On-Site Inspection Program on behalf of the Advanced Research Projects Agency of the U.S. Department of Defense. These were the first field trials to be conducted by the United States. They were designed to apply techniques to test methods of verification of underground nuclear explosions. The field trials were designated Project ARKOSE and Project BRECCIA and were conducted in southeastern Utah and on Amchitka Island, Alaska, respectively.

In fiscal year 1967, Geological Survey personnel, utilizing their experience from Projects ARKOSE and BRECCIA, participated in the design and conduct of follow-up inspection experiments conducted by Project CLOUD GAP of the Department of Defense and the Arms Control and Disarmament Agency. The Survey provided instruction to military personnel in map and aerial photograph reading and in the effects of underground nuclear explosions.

Follow-on field studies to Project BRECCIA were made on Amchitka Island in August 1967. Principal emphasis was placed on the question of the time persistence of nuclear explosion effects as revealed by the tundra vegetation characteristic of Amchitka Island. These studies confirm that tundra vegetation is slow to recover from damage and that evidence of disruption of vegetation persists for many months and probably for many years.

PLOWSHARE PROGRAM

The objective of the PLOWSHARE Program of the Atomic Energy Commission is to develop means of utilizing underground nuclear explosions for peaceful purposes. The Geological Survey contributes to this effort in many 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 highway construction

The Committee on Engineering Geology of the Highway Research Board, whose chairman is Ernest Dobrovolny of the Geological Survey, has studied the feasibility of using nuclear explosions to excavate for highway construction. The Committee report[24] notes that nuclear excavation for highway construction "has a high success potential," and recommends further experimentation to determine the "limits of applicability of the method." Further research and development will improve understanding of the usefulness of nuclear excavation for highway construction and the limitations of the method as controlled by radiation, seismic, and air-blast effects.

Nuclear explosions and development of water resources

Several years ago, the parameters relating to the use of nuclear explosives in the development and management of water resources were outlined.[25] Since then many specific sites and (or) situations in the United States and in a few other countries have been evaluated with the objective of selecting sites for actual demonstration experiments. Very few of the sites are thought to be suitable, principally because unique geohydrologic situations must prevail in order for nuclear explosions to be useful.

One of the most promising applications thus far identified—repressuring in the Dakota artesian basin—has proved upon further analysis not to be practical. Repressuring by conventional wells promises effects equal to those of nuclear detonations at substantially less cost and with greater certainty.

The principal nuclear-explosion effect useful for ground-water management is the rubble-filled collapse chimney. However, many recent tests of nuclear explosives indicate that the upward extent of the collapse chimney is not closely predictable. Accordingly, close matching of chimney height to stratigraphic and aquifer bounds of a particular hydrologic situation is not predictable.

[24] Committee on Engineering Geology—Department of Soils, Geology, and Foundations, 1966, Application of the Plowshare Program of nuclear excavation experimentation to highway construction: Natl. Acad. Sci.—Natl. Research Council, Highway Research Circ. 20, p. 1–10, illus.

[25] A. M. Piper, and F. W. Stead, 1965, Potential applications of nuclear explosives in development and management of water resources—principles: U.S. Geol. Survey TEI–857, issued by Div. Tech. Inf., U.S. Atomic Energy Comm., 128 p.

GEOLOGIC AND HYDROLOGIC EFFECTS OF NUCLEAR EXPLOSIONS

Response of aquifer systems to nuclear explosions

As part of a continuing research program to assess the possibility of permanent changes in aquifer systems in response to seismic motion generated by nuclear explosions, the Geological Survey has monitored selected wells at two locations: The Nevada Test Site and the Tatum salt dome in Mississippi.

The STERLING event, a very low yield nuclear explosion, was fired in a salt cavity formed by a larger and earlier nuclear explosion in the Tatum salt dome, Lamar County, Miss. The pressure response of ground water was measured in 2 wells tapping the limestone caprock of the dome and in 1 well tapping the Miocene sand overlying the caprock. The amplitude of the water-level fluctuation was about the same (5–7 inches) in all 3 wells. However, the frequency of the fluctuation is different, and this difference apparently is a function of the aquifer material and the type of well construction.

The GREELEY event, an intermediate-yield nuclear explosion, was detonated in volcanic tuff in Pahute Mesa at the Nevada Test Site. The response of ground water to the event was measured in 4 observation wells instrumented with pressure transducers and in 12 observation wells with float-operated water-level recorders. The in-close immediate responses of the water columns in 2 wells on Pahute Mesa were 68 and 7.5 feet in addition to seismic-shock motion, several other wave forms, and a long-term (6–24 hr) rise in water level. In more distant wells out to a 75-mile radius, the amplitudes of water-level fluctuations ranged from less than 0.02 foot to about 0.7 foot.

Effects of nuclear explosions on hydrologic systems

The BILBY event, an intermediate-yield nuclear explosion detonated in the zone of saturation at the Nevada Test Site, produced a collapse chimney of much higher transmissibility than the surrounding rock (volcanic tuff). Two postshot drill holes have been used to study the hydrologic and radiochemical changes produced by the explosion. One hole (reentry hole) was drilled directly into the collapse chimney, and the other hole (offset hole) was drilled 400 feet away on the downgradient side of ground zero. Radioactivity logging and analyses of water samples from the offset hole indicate that radioactivity from the explosion is distributed horizontally (parallel to the bedding in the tuff), and is not distributed radially from the shotpoint as had been predicted. After hydrologic testing of the tuff section the offset hole was deepened into the underlying Paleozoic carbonate rock, and the tuff section was cased off. Two hundred thousand gallons of water was pumped from the carbonate aquifer, and analyses were made for radiochemical constituents. No analyses showed radioactive levels above background. No water-level fluctuations were observed in the reentry hole during pumping of the offset hole, indicating that no major hydraulic connection exists between the collapse chimney and the underlying carbonate aquifer.

Response of faults to nuclear explosions

Some underground nuclear explosions cause permanent displacement and movement of natural preexisting faults. Surveys have been made of the permanent surface-ground displacement resulting from many of the large explosions. Geological Survey scientists have analyzed the displacement data by application of dislocation theory and have been able to estimate the depth that specific faults have moved. For example, the DURYEA event at the Nevada Test Site triggered movement of two separate faults. One fault is calculated to have had movement on it to a depth of 1,800 feet; the other fault, though more conspicuous at the ground surface, is estimated to have had movement on it only to a depth of a few tens of feet. The LONG SHOT event on Amchitka Island, Alaska, caused one fault to have movement on it to a depth of about 1,000 feet.

GEOLOGIC, GEOPHYSICAL, AND HYDROLOGIC STUDIES

Supplemental test sites

In October 1966, the Atomic Energy Commission announced that it was going to investigate the suitability of certain areas in the United States as test sites to supplement the capability of the present Nevada Test Site for underground nuclear explosions. Two areas were designated for investigation: central Nevada north of the Nevada Test Site, and Amchitka Island, Alaska. The Geological Survey was authorized to mobilize its scientists to conduct comprehensive investigations and surveys at these two places.

On Amchitka Island, a reconnaissance geologic map was completed, a reconnaissance gravity geophysical survey was completed, hydrologic studies were initiated, and a detailed aeromagnetic survey was made by a contractor. Five sites for exploratory drill holes were selected, and in May and June 1967 two drill holes were started.

In the central Nevada area 6,000 square miles was geologically mapped at a scale of 1:250,000. The same area was reconnoitered by gravity surveys. About half the area was surveyed by magnetometer aerial surveys and by ærial infrared sensors. Hydrologic surveys of the entire 6,000-square-mile area were completed. Ten holes were drilled in different geologic and hydrologic environments to acquire much-needed data on geothermal temperatures, subsurface hydrologic conditions, and characteristics of the rocks at depths in excess of 6,000 feet.

Engineering geology of tunnels

At the Nevada Test Site many thousands of feet of tunnel is being excavated to provide sites for underground nuclear tests and experiments. To obtain geologic and engineering data in order to plan tunnel development in areas that provide suitable sites, geophysicists J. H. Scott and R. D. Carroll have measured the electrical properties and seismic-velocity properties of rocks in the Straight Creek Tunnel pilot bore (Colorado) and in tunnels at the Nevada Test Site. They have related these properties to rock quality, height of tension arch, stable vertical load, set spacing and type of steel support, lagging and blocking, time rate of construction, and cost of construction per linear foot. By geophysical measurements made on the surface, in holes drilled from the surface to the level of a proposed tunnel, or in holes drilled ahead of the face of a tunnel, Scott and Carroll can predict the best route for a proposed tunnel and possibly provide advance data to improve the efficiency of construction and logistic support.

Ground-water hydrology of Pahute Mesa, Nevada Test Site

Pahute Mesa, in the northwest part of the Nevada Test Site, has been developed by numerous drill holes for intermediate-yield underground nuclear tests. R. K. Blankennagel and J. E. Weir have investigated the hydrologic conditions beneath the mesa for several years. They have determined a significant pattern of natural cross flow with changes in head at depth in the mesa. Specifically, all exploratory holes drilled in the eastern part of Pahute Mesa, except one, have a stable head from the static water level down through the intervals of maximum permeability and decreasing head below that to the total depth, or have decreasing head from the static water level to the total depth. Conversely, holes drilled in the western part of Pahute Mesa have a variable head from the static water level through the intervals of maximum permeability and an increasing head below that to the total depth. These differences in hydrologic conditions between the eastern and western parts of Pahute Mesa are inferred to be related to differences in rock type and rock structure in the mesa.

The principal direction of ground-water flow in the mesa is to the south and southwest. Hydrologic gradients are gentle in those rocks with high resistivity ranges (rhyolites) and are relatively steep in those rocks with low resistivity ranges (zeolitized tuffs).

Ground-water inflow to a chamber mined at a depth of 2,200 feet below the water table in Pahute Mesa was studied in August and September 1966. The chamber is approximately cylindrical, with a diameter of 16 feet and a height of 30 feet. The rock surrounding the chamber is ash-fall tuff of very low permeability. Upon completion of the chamber, water entered at a rate of 180 gph and the rate stabilized at 65 gph after 10 days. Entry of water to the chamber is controlled by the degree to which fractures in the tuff have been healed by argillization and zeolitization. Most of the fractures are sealed by fine-grained secondary minerals and these do not yield water, but a few of the fractures that are not filled by secondary minerals yield virtually all the water entering the chamber.

DISPOSAL OF RADIOACTIVE WASTES

Radioactive materials in suspension or solution are discharged to the environment as a result of a wide variety of nuclear-energy activities. Research of the Geological Survey sponsored by the Atomic Energy Commission has included (1) transport by streams, (2) ground-water transport, and (3) studies related to new waste-disposal methods and techniques.

TRANSPORT OF RADIONUCLIDES BY STREAMS

Columbia River and estuary

Radionuclides in the Columbia River below the AEC sites at Hanford, Wash., originate from the irradiation of dissolved mineral matter in water used to cool the reactors. The reactors were shut down for a 46-day period in July and August 1966, thus providing an opportunity to study the effect of the reduced rate of radionuclide input to the river.

It was found that during the shutdown, radionuclide concentrations in the top layers of sediment in the bottom of the river decreased with time, whereas at comparable times during normal operations, radioactivity in the streambed sediments increased with time. In other studies of bottom sediments it was found that in the underwater sand dunes radioactivity becomes uniformly mixed from the level of dune trough to crest. This is not true in areas of sediment deposition; there the radionuclides are found mostly in the top few inches of sediment, and concentrations decrease sharply with depth below the streambed.

Other work on the river included a dye-tracer test at the confluence of the Snake River with the Columbia to study mixing processes as the two streams enter McNary Reservoir. Nearly a ton and a half of rhodamine-B dye was used. Water samples were taken from boats and analyzed immediately by fluorometric methods. Aerial photographs taken from Geological Survey aircraft aided in following the dye cloud downstream.

In the Columbia River estuary, from Vancouver, Wash. to the Pacific Ocean, the transport and deposition of radionuclides are under investigation by using new sophisticated hydraulics techniques, mapping depositional environments, and obtaining data on mineralogical, chemical, and physical properties of sediments which influence or control deposition.

In connection with the development of a radionuclide inventory in the estuary, the water discharge is being measured at two sections with a moving-boat technique that makes it possible to define vertical velocity distributions at 20 locations across a 4-mile-wide section in slightly over 1 hour. Data from the measurements are used in the development of mathematical models for computing continuous records of discharge from stage records. Radionuclide concentrations determined from samples of water and sediment are used, with water discharges, to compute radionuclide loads for the inventory.

In general, main channels and large areas of adjacent tide flats are mainly sand and have low levels of radioactivity; minor channels and large areas of tide flats in bays peripheral to the main channels have high levels of radioactivity and are mostly silt and clay. In the bay areas, transport of radioactive sediments occurs mainly during times when flood tides are accompanied by strong onshore winds.

Clinch and Tennessee Rivers

U.S. Geological Survey contributions to the comprehensive study of the transport of radionuclides by the Clinch and Tennessee Rivers are summarized in the final report of the Clinch River Study Steering Committee.[26] This multidiscipline investigation included studies of uptake, cycling, and effects of radionuclides on river biota, and estimated radiation doses to man from several different sources, such as intake of contaminated water or fish, in addition to the hydrologic phenomena which were the Survey's principal interest.

[26] Clinch River Study Steering Committee, 1967, Comprehensive report of the Clinch River study: Oak Ridge Natl. Lab. [Tennessee], ORNL–4035, 121 p.

The study reached the conclusions, among others, that (1) river water is the principal medium for transporting radionuclides and the most important vector for radiation exposure to the general public, (2) bottom sediments provide only a negligible source of radiation to man, (3) consumption of fish flesh in 1960 to 1963 could have caused a dose approximately equal to the ingestion of water, and (4) a dependable, standardized monitoring system should be continued. The general conclusions of the steering committee could not have been reached without the detailed investigations of bottom sediments reported by P. H. Carrigan, Jr., and R. J. Pickering (r2054), Carrigan and others (r1524), and Pickering and others (r1990).

TRANSPORT OF RADIONUCLIDES BY GROUND WATER

National Reactor Testing Station, Idaho

Study of the hydrology of volcanic rocks and associated alluvial deposits at the National Reactor Testing Station (NRTS), Idaho, placed emphasis on recharge from Big Lost River and its effect on the aqueous transport of radioactive wastes that are discharged to the ground. J. T. Barraclough and others (r1299) found that the high flow of 1965 (almost 400,000 acre-feet of water at Mackay Reservoir), much of which infiltrated the streambed, caused the water table to rise more than a foot over more than two-thirds of the 894-square-mile area of the NRTS. In the west-central part of the area water levels in wells rose more than 6 feet, and thus altered, temporarily, the hydraulic gradient in the Snake River Plain aquifer.

The effect of this change in gradient on the migration of tritium, the principal constitutent of radioactive wastes that are discharged to the 600-foot disposal well at NRTS, are being studied further. Tritium has moved farther than any other radionuclide and is now detectable about 4 miles south of the disposal well. On the other hand strontium–90, which has been discharged to the well in relatively small quantities, has been detected in ground water no farther away than 2,335 feet south of the disposal well.

STUDIES RELATED TO NEW WASTE-DEPOSAL METHODS AND TECHNIQUES

National Reactor Testing Station, Idaho

The prospect of disposing of radioactive gases by injecting them into the ground has been under study by the Atomic Energy Commission and its contractors. One of the phenomena that must be understood before this disposal method can be utilized is the interchange of air between the atmosphere and air-filled voids below the surface in response to barometric changes.

Air-filled openings in the basaltic rocks that are penetrated by a well have been known to receive air from the atmosphere or to force air from underground into the atmosphere in response to pressure gradients. One approach to studying the phenomenon has been to measure and record the temperature, relative humidity, and flow velocity of air that enters or leaves a well open to air-filled voids in the subsurface. J. T. Barraclough and others modified conventional equipment for the purpose and have found that where ground water is 180 feet below the surface, air expelled from the uncased well is at a temperature of 42°F and is nearly saturated with water vapor.

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. Both inorganic and organic substances may have a detrimental effect upon the water resource.

INORGANIC MATTER IN WATER

Acid mine drainage in western Kentucky

H. F. Grubb and P. D. Ryder have identified Buffalo, Cany, and Hurricane Creeks as major contributors of acid coal-mine drainage to the Tradewater River in Hopkins County, Ky. Concentrations of sulfate in the waters of the area were used to define the magnitude of the acid problem.

Although total coal production in the upper Tradewater basin has declined sharply since 1950–52, the sulfate content of the upper Tradewater River increased significantly in 1955 and has remained high because of the highly mineralized acid discharges from abandoned and active mines.

The sulfate content of the flow from the Buffalo Creek subbasin, where only surface mining has occurred, ranges from 530 to 2,500 ppm; concentrations of a similar magnitude emanate from the Cany Creek subbasin, which has undergone both surface and underground mining. Downstream from these tributaries, the sulfate content and acidity of the Tradewater River is reduced somewhat by the inflow of alkaline streams.

Ground-water contamination in northwestern Oregon

Contaminants in ground water in a shallow aquifer at North Salem, Oreg., have dispersed and affected nearby domestic water supplies, according to Don Price (p. B217–B220). In 1946, the aquifer was contaminated by the disposal of industrial waste in a residential area, and the sulfate content of the ground-water exceeded, 1,000 ppm locally. From 1947 to 1964 the contaminants, while becoming naturally diluted at the disposal site, dispersed into the aquifer downgradient for about 1 mile. The highest sulfate content observed in the area in 1964 was 140 ppm.

Salt-water encroachment in South Carolina

Salt-water encroachment has a detrimental effect on the quality of surface water in the South Edisto River estuary in southern South Carolina, according to T. R. Cummings. Chemical-quality data collected since 1958 show that salt water intrudes the lower 25 miles of the river about 50 percent of the time; the encroachment is related directly to the discharge of the river. During periods of low flow, or about 7 percent of the time, the quality is impaired for most uses. At average discharge (2,652 cfs) the specific conductance of the water does not exceed 250 μmhos, but during low flow (700 cfs) the conductance is as great as 10,700 μmhos.

Chloride contamination in Caloosahatchee River, Fla.

Two sources of salt-water contamination of the Caloosahatchee River in southern Florida have been identified by D. H. Boggess. The primary source of contamination is salt water moving upstream from the tidal portion of the river during periods of low river discharge. The river is also contaminated by ground water with an average chloride content of about 1,000 ppm, from wells drilled to the Floridan aquifer.

The combined sources of contamination caused the chloride content in the deeper parts of the river to increase from 70 ppm in November 1966 to more than 300 ppm in January 1967. Previous data indicate that the chloride content may exceed 2,000 ppm after extended periods of deficient discharge.

The contamination problem is significant because both the city of Fort Myers and Lee County plan to use the river as a major source of water supply.

(For sea-water intrusion in Puerto Rico, see "Puerto Rico and Virgin Islands" in section "Water Resources, Atlantic Coast Region.")

Proposed reduction of salt-water intrusion in New Jersey

The hydrologic effects of a proposed impoundment of fresh surface water in Bidwell Ditch Basin, a small tidal basin on the Cape May peninsula of New Jersey, is being studied by J. G. Rooney. Three aquifers would be affected in the unconsolidated sediments underlying the basin to about 200 feet below the surface. Vertical leakage occurs between the three aquifers. Tidal marshes and swamps make up much of the lower parts of the basin, and the quality of water in the streams is similar to that of Delaware Bay. In the headwater areas, stream quality is similar to that of the fresh ground water. Because of the very small gradients and shallow depths to water in the water table, much of the ground-water discharge in the tidal marshes is discharged from the basin by evaporation and transpiration. Some is discharged to the stream channels in the upland but is eventually evaporated or dissipated in dilution with the salty tidal inflow. Most of the ground water is fresh. Salt-water intrusion in the three shallowest aquifers is limited to the water table in the tidal marshes and directly beneath the tidal stream channels. If fresh water is impounded, additional fresh-water recharge into the Tertiary Cohansey Sand from the two shallower aquifers above would occur and the threat of salt-water intrusion in the ground-water supplies would be reduced. (See also "Estuarine Hydrology" in section "Investigations of Principles and Processes, Marine Geology and Hydrology.")

ORGANIC MATTER IN WATER

Pesticide study in western Tennessee

The subsurface movement of pesticides in ground water is being investigated by D. R. Rima in Hardeman County, Tenn. Chlorinated hydrocarbons from a pesticide waste-disposal site have moved downward vertically from the burial trench to the water table, a distance of more than 30 feet. The maximum depth to which the contaminants have or will descend is unknown; however, no evidence of lateral movement was found.

Phenols in streams of northeastern New Jersey

The phenol content of streams has been determined for 15 locations in notheastern New Jersey. At most sites the phenol content was less than 10μg per l. However, at 2 sites on the lower Raritan River, maximum concentrations exceeded 175 μg per l, according to P. W. Anderson and S. D. Faust. These concentrations were determined while testing the applicability of the 4-aminoantipyrine colormetric method and extraction techniques to natural water.

Carbon on suspended sediment in New Jersey streams

Organic material adsorbed to suspended-sediment particles in streams consumes oxygen and increases the biochemical-oxygen demand. For streams in New Jersey, P. W. Anderson and A. N. Ott analyzed sediment from nine sites for "readily oxidizable carbon." The normal range of carbon content was found to be 5 to 15 percent of the sediment. However, for streams in southern New Jersey, more than 50 percent of the sediment content was carbon. The carbon sources are probably organic iron complexes and vegetal materials in the stream sediments.

Ground-water contamination on Long Island

A shallow water-table aquifer in adjoining sewered and unsewered parts of southern Nassau County, N.Y., shows a wide range in concentration and distribution of contaminants. Contamination of the ground water is due to cesspools, industrial wastes, and fertilizer in both areas, according to N. M. Perlmutter. Concentrations of pollution indicators, such as chloride, nitrate, and detergents, generally were greater in the unsewered area. Coliform-bacteria counts were insignificant at most localities.

Nitrate contamination in Nebraska

Nitrate in ground water is a problem in Holt County, Nebr., according to R. A. Engberg. At one-third of the wells sampled, nitrate concentrations were greater than the 45 mg per 1 safety limit recommended by the U.S. Public Health Service. The major sources of the nitrate are the decomposition products of plant and animal wastes in farmyards, feed lots, silage pits, and septic tanks. Nitrate fertilizers also are possible sources.

DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH

The U.S. Geological Survey is continuing to cooperate on environmental studies with health agencies. For example, information on the possible extent of a chromium deficiency in plants and soils of Colorado was compiled to aid in investigation of a deficiency disorder in children. Information on "background" lead in the environment is being acquired from samples collected during Wilderness and Primitive Area studies. Cooperative investigations with personnel of the U.S. Public Health Service will study the significance of background lead on public health.

Relation of soil to cardiovascular mortality

A cooperative project with the Public Health Service continued during 1967, and statistical studies are being completed of the relation between the composition of cultivated soils and garden vegetables in areas of high cardiovascular mortality but otherwise generally low mortality. It appears that amounts of certain elements in cultivated soils can be used to distinguish, precisely, areas of different cardiovascular mortality rates. Analyses of vegetables show strong trends in distribution of elements which characterize the high and low mortality areas. Statistical studies of the element distribution in uncultivated soils and native plant samples, though not yet completed, are contributing to an understanding of cardiovascular diseases and disorders.

Minor-element content of Denver, Colo., water supply

In order to study the minor-element content of the Denver public water supply, samples of both raw and finished water at each of the city's 5 treatment plants were analyzed monthly for a period of 5 months (May through September 1966). The major constituents were determined by emission spectroscopy and by atomic-absorption spectrophotometry.

Each sample was examined for the possible presence of more than 20 minor elements. Eleven, including Al, Ba, B, Cu, Fe, Li, Mn, Mo, Rb, and Sr were found in all or nearly all the samples. Cr, at concentrations of 7 ppb or less, was found in both the raw and finished water at one of the treatment plants, and up to 3 ppb Ti was found in samples collected at another.

With the exception of Al, Mo, and Sr, the concentrations of the trace elements never exceeded 100 ppb during the 5-month period. Al and Sr concentrations as high as 200 and 400 ppb, respectively, were commonly recorded. Traces of Mo were found in all samples, and in samples collected at 4 of the 5 treatment plants, Mo concentrations ranged from 140 to 260 ppb.

PROBLEMS IN ENGINEERING GEOLOGY AND HYDROLOGY

URBAN STUDIES

Engineering-geology maps prepared for Northeast Corridor

Geologic maps of the Northeast Corrider, the highly urbanized area between Washington, D.C., and Boston, Mass., have been compiled by the Geological Survey at a scale of 1:250,000 on behalf of the U.S. Department of Transportation, which is making plans for a possible high-speed ground transportation system to link metropolitan centers in the area. One 5-sheet geologic map that covers an area of roughly 25,000 square miles shows bedrock formations; another shows the distribution of Coastal Plain sediments and surficial deposits. Each map is accompanied by cross sections and a table describing physical properties and engineering characteristics of the map units. Four other maps at a scale of 1:1,500,000, each accompanied by a text, delineate earthquake epicenters, locate excavations and borings that provide engineering data on rocks, and provide an index to the published geologic maps that were used in the compilation. A short text gives estimates of the geothermal gradients along the corridor. The report, which has been published as Geological Survey Miscellaneous Geologic Investigations Maps [27] will be used as source material for planning and feasibility studies, and will serve a variety of other engineering and educational uses.

Potential geologic hazards at Juneau, Alaska

Studies by R. D. Miller in the Juneau, Alaska, area indicate that mass wastage on the steep mountain sides above Juneau is one of the greatest potential geologic hazards to the community. In the last 2 decades several debris flows arising from rain-soaked talus and glaciomarine till have invaded the town. Large boulders riven from jointed bedrock frequently roll down the mountainsides into a basin east of town, where they have been accumulating since before Juneau was settled. Snow avalanches also sweep down the mountain slopes from time to time, one of the most recent ones having descended into the northern part of Juneau in 1962. A strong earthquake in the Juneau area could release destructive debris slides, debris flows, rockfalls, and snow avalanches that might endanger lives and property.

Rockslides near Anchorage, Alaska

Rockslides are a major hazard in several sparsely populated valleys in the Chugach Mountains in the Greater Anchorage Borough being mapped by Ernest Dobrovolny and H. R. Schmoll. Some lakes previously thought to be impounded by moraines are dammed by Recent rockslides. Some slides were triggered by the 1964 Alaska earthquake, but none of these were large enough to dam streams in the valleys. Several sites of potential future rockfalls or rockslides have been identified. In the event of another great earthquake, the danger from slides probably would be as great as that from foundation failures.

Site of Boston, Mass., was determined by availability of water

Historical records show that Boston was settled at a site chosen principally because good spring and well water were available. Studies by C. A. Kaye of deep excavations for new buildings in the old section of the city reveal the hydrogeologic cause. A large delta of highly porous gravel beneath a layer of till underlies the northeastern flank of Beacon Hill from Scollay Square to Boston Common. Somewhat younger water-bearing gravels beneath clays underlie the Cambridge Street area farther west.

[27] U.S. Geological Survey, 1967, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Massachusetts: U.S. Geol. Survey Misc. Geol. Inv. Map I-514-A, B, C. [Published July 1967]

TOPICAL STUDIES

Earthquake hypocenters located by refined plotting technique

A refined plotting technique for locating earthquake hypocenters has recently been developed by C. R. Dunrud and B. K. Barnes for seismic studies in the Sunnyside mining district of east-central Utah where coal-mine bumps have been a recurring problem. Delay-time curves, based on a detailed knowledge of stratigraphic and structural relations in the district, incorporate seismic-velocity data gained from seismic-refraction surveys.

The improved plotting technique was applied to an analysis of seismic activity that occurred during the first week of January 1967, when the greatest number of large-amplitude earthquakes in the 4-year history of the seismic recording network was registered in the southern part of the mining district. During this period, bumps in the coal mines were more frequent and intense than usual in this part of the district, and a relationship of bumps to seismicity seems probable. All the large-amplitude tremors originated in 2 zones, each about 1½ square miles in area. One zone, elongate in a north-northwesterly direction, is 3-dimensional, lying 5,000 to 10,000 feet below the level of the southernmost mines of the district. This zone is very close and subparallel to the projected plane of a large buried fault. Earthquakes in this zone probably resulted from release of natural stresses. The second zone, planar and triangular in ground plan, is in the middle of the mining district near the level of current mining. Numerous parallel faults in this zone extend up to the ground surface, and a large percentage of the earthquake hypocenters in this zone coincides with these faults near the mine level. These tremors therefore probably were induced by stress redistribution as a result of mining.

Slope stability of coal-mine dumps

Potential instability was noted in 30 of the 38 coal-waste dumps in southern West Virginia evaluated by W. E. Davies and J. T. Gallaher in cooperation with personnel of the U.S. Bureau of Mines who had previously recognized signs of instability. The dumps are 100 to 500 feet thick and as much as 3,500 feet long. Although the maximum height of any dump is 800 feet, most are 200 to 450 feet high. Half the dumps examined are on hillsides, but others extend across the mouths of small valleys.

One cause of potential instability is the blockage of drainage behind or on top of 12 dumps. A lake impounded by heavy rain could overflow a dump, erode through the coal waste, and precipitate sliding or flowage of the waste. Overloading exists at five locations where tram dumps and piles of filter cake have been placed on older waste piles. In six burning dumps, explosions have caused mudflows. Five dumps have been built on unstable natural slopes.

Most of the waste piles have slopes of 35°–37°, which is the angle of repose of the dry waste. Some dumps have failed by slumping along curved surfaces of rupture. Slump blocks as much as 500 feet wide and 200 feet high involve as much as 100,000 cubic yards of material.

LAND SUBSIDENCE

Studies of land subsidence caused by decrease of head in aquifer systems are continuing in California, Nevada, Arizona, and Texas. These studies are contributing to knowledge of the physical, mechanical, and hydrologic properties of leaky and compressible aquifer systems, the storage characteristics of semipervious interbeds and confining beds, the change in the coefficient of storage with time and change in applied stress, and to the improvement of methods for estimating and controlling subsidence.

Subsidence rate decreasing in west-central San Joaquin Valley, Calif.

Comparison of U.S. Coast and Geodetic Survey adjusted leveling data of March 1963 to that of March 1966 in the Los Banos–Kettleman City area, west-central San Joaquin Valley, indicates that maximum subsidence was 3 feet, or 1 foot per year. In most of this area of 1,500 square miles, subsidence in the 3 years ranged from 0.5 to 2.0 feet; it exceeded 2 feet in a strip 50 miles long by 2 to 9 miles wide, about 7 miles northeast of the western foothills and traversed by the San Luis Canal–California Aqueduct. In much of the area, subsidence was continuing at about the same rate as that between December 1959 and March 1963, but in the central strip of most rapid subsidence, the 3-year amount had decreased 0.5 to 1.5 feet compared to that of 1959–63. Maximum historic subsidence since the 1920's has occurred 7 miles southwest of Mendota: in 1963 it was 23 feet (J. F. Poland and R. E. Evenson, r0862) and by 1966 had reached 26 feet. At that place, all the subsidence is due to compaction of the aquifer systems in response to head decline.

Prehistoric near-surface subsidence cracks in western Fresno County, Calif.

W. B. Bull (r0853) examined abundant clay-filled cracks that were mapped by U.S. Bureau of Reclamation geologists in the trimmed banks of the San Luis Canal where it crosses the alluvial fan of Panoche Creek in western Fresno County, Calif. He concluded that the clay-filled cracks have characteristics similar to those of known present-day near-surface subsidence cracks but that they were formed due to wetting as a result of prehistoric streamflows on the fan. The erratic areal distribution of the stream percolation left a few pockets of deposits susceptible to compaction due to wetting. Such pockets, if they existed along the canal alinement, probably have been wetted by agricultural operations, but as much as 3 to 4 feet of subsidence may occur locally upslope from the canal when areas that have never been irrigated are first wetted with canal water.

Increased rate of subsidence in Santa Clara Valley, Calif.

Releveling of the subsidence-level network between Redwood City, Niles, and San Jose in the Santa Clara Valley was completed by the U.S. Coast and Geodetic Survey in March 1967. Preliminary analysis of unadjusted field elevations by J. F. Poland indicates that since 1960, the last prior releveling of the net, bench marks in downtown San Jose have subsided as much as 3.6 feet and bench marks at Alviso (near tideland, at the south end of San Francisco Bay) as much as 2.2 feet. The average rate of subsidence in San Jose since 1960 is 0.6 foot per year—the most rapid to date—as compared with 0.25 foot per year for the period 1954–60. Total subsidence since 1912 now is 12.7 feet (bench mark P7), all attributed to artesian-head decline and resulting increase in effective stress.

Compaction of sediments in subsiding areas in central California

R. H. Meade [28] has studied the compaction of the fresh-water-bearing sediments buried 100 to 2,000 feet below the land surface in the San Joaquin and Santa Clara Valleys, Calif. Part of this compaction has been the natural effect of progressive burial of the sediments as newer sediments were deposited above. And part of it has been manmade, the effect of reducing fluid pressure in the ground-water reservoirs. He finds that the increase in effective overburden load, due to both causes, has compressed the sediment volume by 10 to 15 percent. Although the load of the overlying sediments is the primary agent of compaction, the porosity and water content of the sediments are also influenced by the size and sorting of the particles, the clay minerals, and the dissolved solids in the water.

Compaction, rebound, and clay minerals in central Arizona

Three compaction recorders installed by the Geological Survey in subsiding ground-water basins in central

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

Arizona in March 1965 have registered appreciable compaction. Well B–2–1 (6dbb), 19 miles west of Phoenix, is 832 feet deep. Well D–2–6 (11bab), 2 miles south of Higley, is 804 feet deep. Well D–7–8 (31bba), 1 mile north of Eloy, is 830 feet deep. Measured compaction in these 3 wells to March 1967 was 0.78, 0.30, and 0.35 foot, respectively. At Higley and Eloy, substantial winter rebound (expansion) of the sediments accompanying water-level recovery has been recorded. For example, the rebound from September 1966 to January 1967 (peak) was 15 and 26 percent, respectively, of the summer compaction (0.13 and 0.19 foot, respectively) from March to September 1966.

H. C. Starkey has made clay-mineral analyses for 14 core samples from 504 to 1,675 feet below land surface in upper Cenozoic continental sediments tapped by water wells in the subsiding Eloy area. He reports that about 6 parts in 10 of the $<2\mu$ fraction is montmorillonite, about equal to the proportion in fine-grained sediments in subsiding areas in central California and in the Gulf coast at Clear Lake, Tex. Compared with the other common clay minerals, montmorillonite is particularly sensitive to changes in effective stress—it compacts the most under increased stress.

New subsidence findings in Houston district, Texas

The relation between the amount of subsidence and water-level decline ranges from less than 0.5 foot subsidence per 100 feet of water-level decline in the Katy area to about 1.3 feet per 100 feet in the Pasadena area, according to R. K. Gabrysch (r1296). The difference can probably be attributed to the differences in the amount of clay present in the zone affected by the pressure decline, as the Katy area is underlain by a greater percentage of sand.

Even though there have been fluctuations in the rate of water-level decline, the subsidence rates apparently have not been affected. It appears that there is a substantial lag in the time between water-level decline and subsidence. It is likely that compaction and subsidence will continue for some time after any stabilization of water levels.

FLOODS

Three major categories in the study of floods by the U.S. Geological Survey are (1) measurement of stage and discharge, (2) definitions 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 1966–67, flood frequency, and flood mapping.

OUTSTANDING FLOODS OF 1966–67

Floods of February 1966 in north-central States

Rains and snowmelt followed by a severe drop in temperature caused large ice jams and flooding on some rivers in the north-central States. A serious flood threat occurred on the Mississippi River near Rock Island, Ill., when a 10-mile-long ice jam formed—the largest ice jam on the upper Mississippi River since the late 1800's. Many people were evacuated from residential areas in flood plains in Illinois and Iowa.

Floods of March 1966 in Georgia

In Georgia heavy rains in early March caused floods having probable frequencies of recurrence of over 50 years. Some 15 counties in the coastal plain were classified as flood-disaster areas.

Texas floods of April 1966

Torrential rains, as much as 20 inches in 3 days, sent streams in north and east Texas on a rampage that killed 11 persons. Major floods occurred in the Sulphur, Sabine, Trinity, and Brazos River basins.

In the greater metropolitan Dallas area, a peak discharge of 16,000 cfs occurred from a drainage area of 10 square miles. The second greatest peak rate of runoff ever recorded in Texas (3,160 cfs per sq mi) occurred from 1.51 square miles within the 10-square mile area. Data obtained from 25 recording rain gages, 6 streamflow gages, 6 partial-record crest-stage gages, and a dense network of flood-profile crest-stage gages indicate that urban development greatly increases the magnitude of peak flood discharges, according to a report by W. B. Mills and E. E. Schrœder (r1277).

Floods of June 24–25, 1966, in southwest and central North Dakota

Major flooding occurred on June 24 and 25, 1966, over an area of 1,600 square miles in southwest and central North Dakota as a result of a 2-hour rainstorm that produced 13 inches of precipitation at the storm center. The intensity of the storm is emphasized by comparing the precipitation with figures in a report by the U.S. Weather Bureau showing the 100-year 2-hour precipitation for the storm area to be 3 inches. Most of the streams in the area had peak discharges in excess of that for the 50-year flood. Highway and agricultural damage was great, but there was no loss of human life.

Floods of December 1966 in southern California

A warm intense storm on December 5–6, 1966, caused record-breaking floods in the Buena Vista Lake, Tulare Lake, and Salinas River basin of southern California.

Resulting flood-peak discharges were over twice as great as previous maximums during 60-year records on the Kern and Tule Rivers. Damage was extreme to all structures along stream channels.

Floods of March 1967 in West Virginia and Pennsylvania

Heavy precipitation concurrent with snowmelt during the period March 5–8, 1967, caused severe flooding over most of West Virginia. Property damage was heavy, and 2 lives were lost; 29 of the 55 counties in the State were declared disaster areas. During the same period, record peak flows occurred at many points in the Monongahela River basin in Pennsylvania.

FLOOD FREQUENCY

Nationwide flood-frequency project

The last of the series of flood-frequency reports consisting of 19 volumes that together cover the entire conterminous United States was completed in April 1967. Each report is for a part corresponding to a major drainage-basin subdivision of the country used by the Geological Survey. Seventeen volumes had been published previously, and two were published this year: Parts 2–B (H. H. Barnes, Jr., and H. G. Golden, r1738) and 6–A (J. L. Patterson, r0389).

Hydrologic data in small drainage basins in Mississippi

As a part of flood-frequency studies in small drainage basins, preliminary analysis of rainfall and runoff data collected from 95 basins less than 2 square miles in area indicates that 1 rain gage at the outlet does not always represent the rainfall distribution over the entire basin. According to J. W. Hudson, however, the single rain gage is probably adequate for computing basin lag time. The data also indicates that vegetal cover may be one of the dominant factors affecting peak runoff from small streams in Mississippi.

Flood-frequency relations for Ohio streams

A published report by Cross and Webber [29] on the magnitude and frequency of floods in Ohio is being updated as a result of a current study by W. P. Cross on methods of estimating the magnitude of floods of selected frequencies at ungaged sites. Correlation of flood peaks with drainage-basin characteristics has been used to give reasonably reliable estimates for areas exceeding 30 square miles. Analysis of data now being collected indicates that correlation procedures will provide reliable results for drainage areas as small as 2 square miles, and results of less accuracy for smaller drainage basins and basins of steep topography.

Flood-frequency relations in Iowa

H. H. Schwob has updated the flood-frequency report for Iowa (r0587), incorporating an additional 15 years of record at 147 gaging stations plus flood records for partial-record stations. Multiple-regression analyses were used to define the magnitude of the mean annual flood for two index regions. Variables found significant in the regression equation for a large central region of the State were drainage area, stream slope, and average annual precipitation (1931–60); only drainage area and stream slope were found significant for the rest of the State. Results are applicable to gaged and ungaged areas ranging from 1 to 14,000 square miles. The report is in two parts: part 1 (text), and part 2 (basic data).

FLOOD MAPPING

Flood maps of urban areas

Maps showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published during the current year as Hydrologic Investigations Atlases for the following areas: Wauconda, Ill. (H. E. Allen, r0125); Lake Zurich, Ill. (A. W. Noehre and R. T. Mycyk, r0687); Steger, Ill. (H. E. Allen, r0032); Normantown, Ill. (V. J. May, r0297); Manhattan, Ill. (H. E. Allen and R. T. Mycyk, r0414); Antioch, Ill. (A. W. Noehre and G. L. Walter, r0029); Sugar Grove, Ill. (H. E. Allen, r0416); Plainfield, Ill. (V. J. May and R. J. Schafish, r1191); Elburn, Ill. (H. E. Allen, r0375); Pingree Grove, Ill. (H. E. Allen, r1283); Dallas, Tex. (F. H. Ruggles, Jr., and C. R. Gilbert, r2031); Kahaluu, Oahu, Hawaii (M. M. Miller, r0028); Dallas, Tex. (F. H. Ruggles, Jr., r0417); Easton, Pa.,–Phillipsburg, N.J. (G. M. Farlekas, r1653); and Conshohocken to Philadelphia, Pa. (A. T. Alter, r1464).

The flood-mapping program in cooperation with the Northeastern Illinois Metropolitan Area Planning Commission, initiated in July 1961 with plans for mapping 43 quadrangles, has been expanded to include 19 additional quadrangles. As of May 1, 1967, hydrologic atlases had been published for 40 of the quadrangles.

Work is also currently in progress toward preparation of flood-inundation atlases for Puerto Rico, New Jersey, Nebraska, Pennsylvania, and Ohio.

[29] W. P. Cross and E. E. Webber, 1959, Floods in Ohio, magnitude and frequency: Ohio Dept. Nat. Resources, Div. Water Bull. 32, 325 p.

REGIONAL GEOLOGY

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

The systematic description and mapping of rock units to show local and regional relations likewise constitute a major scientific objective. Mapping the geology of the United States is a mandate of the Organic Act establishing the Geological Survey, and the completion of geologic maps for the country at scales that will fulfill foreseeable needs and uses is a long-range goal. A summary of recent results of this mapping, especially in the fields of stratigraphy, structural geology, and regional geophysics, is discussed here according to subdivisions of the conterminous United States shown on figure 2.

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 makes up an important part of the U.S. Geological Survey's program. Mapping at this scale started in a small way

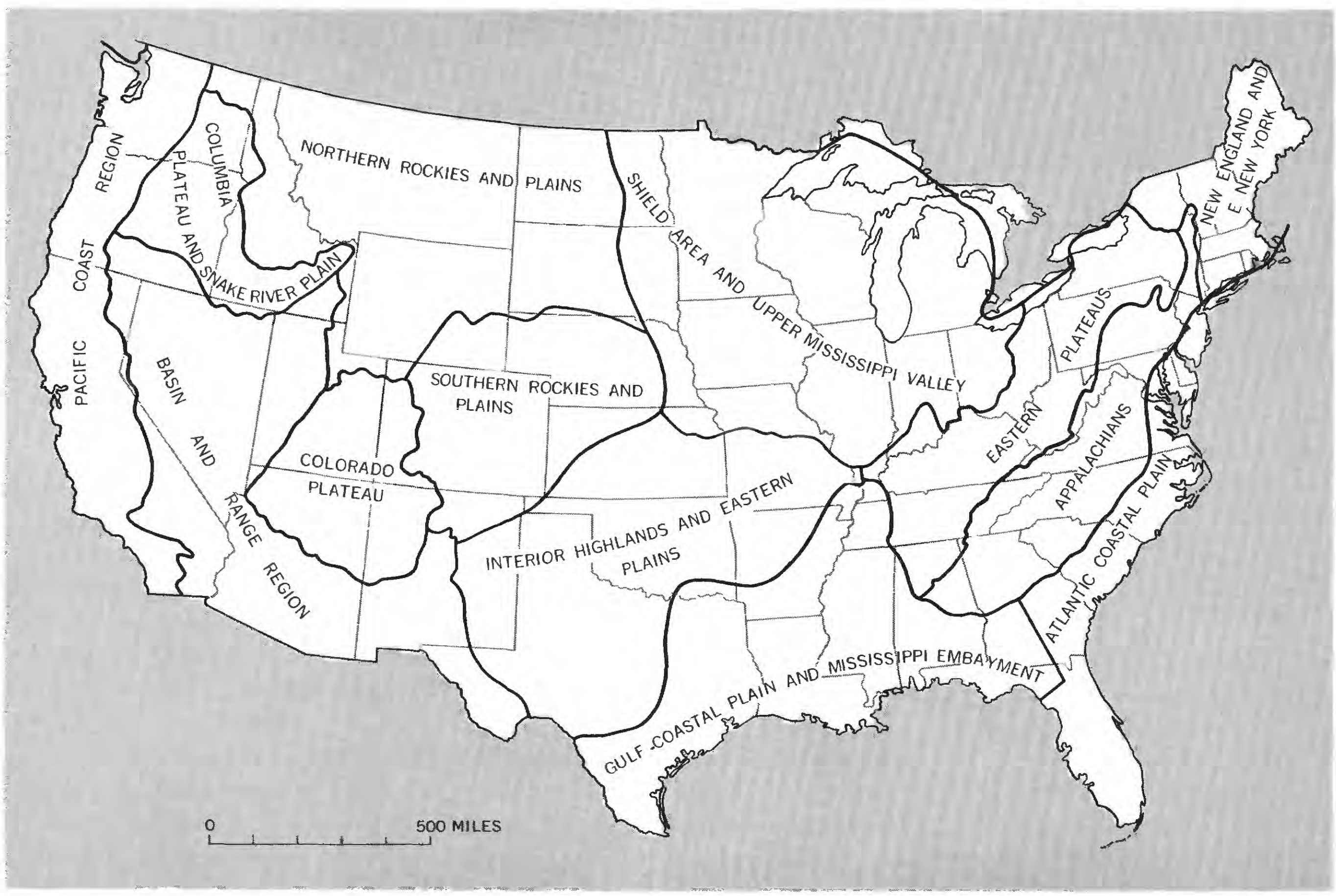

FIGURE 2.—Index map of the conterminous United States, showing boundaries of regions referred to in discussion of regional geology.

many years ago and has now expanded to a point where it constitutes about one-fifth of the regional geologic-mapping program. Many State geologic surveys also have 1:250,000-scale geologic-mapping programs underway or completed. This joint effort by the Federal and State Surveys as a nationwide program promises to provide intermediate-scale geologic-map coverage of two-thirds of the United States by 1985.

The U.S. Geological Survey is participating in 1:250,000-scale geologic-mapping programs that will provide extensive or complete coverage of Alaska, Nevada, Colorado, and Nebraska within a few years. Single-sheet 1- by 2-degree geologic maps have been started in parts of Washington, Oregon, Idaho, Montana, Wyoming, Utah, Arizona, New Mexico, Iowa, North Carolina, South Carolina, Tennessee, and Virginia. Figure 3 shows the status of 1:250,000 geologic mapping in the conterminous United States, Alaska, and Puerto Rico.

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, some of which were described in earlier pages. This geologic mapping contributes to coverage of the United States and will be available for use in compiling 1:250,000 quadrangle maps at a later date.

The 1:250,000-scale geologic maps have a variety of uses. They help define areas where need for larger scale maps is most critical, and they direct attention to broad geologic problems involving large segments of the earth's crust. They have already proved to be ideal for geologic analysis of major tectonic and stratigraphic problems, for analysis of mineral provinces, and for relating broad geophysical anomalies to surface geology. They form an integral part of the Transcontinental Geophysical Survey for the International Upper Mantle Project and are an indispensable aid in interpreting the structural relationships across the entire continent.

Additional scientific results of the 1:250,000 mapping program are reported by geologic provinces in the following pages, along with the results of other programs.

MAPS OF LARGE REGIONS

The U.S. Geological Survey publishes a number of geologic and geophysical maps of national or international scope. These maps of large regions bring together great amounts of information from many sources—studies by Geological Survey personnel, and published or unpublished information supplied by geologists of State geological surveys, private companies, and universities. These small-scale compilations provide regional geologic patterns and relations which may be compared and correlated with many kinds of earth science data.

Cooperative projects

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

A basement-rock map of North America between lat. 24° and 60° N. was published in early 1967 at a scale of 1:5,000,000 (Am. Assoc. Petroleum Geologists and U.S. Geol. Survey, r0671). This map, on which the Geological Survey collaborated, was compiled by the Basement Rock Project Committee of the American Association of Petroleum Geologists, with P. T. Flawn, University of Texas, as chairman. By contours the map shows the altitude of the upper surface of the basement as determined from wells, geophysical measurements, and geologic inference. The map also shows the age of the exposed basement rocks by colors and the gross lithology of the exposed basement rocks by black-overprint symbols. Major faults and zones of abrupt dislocation are shown, as well as the locations of wells penetrating the basement. The map is a single sheet measuring 40 by 53 inches.

Other cooperative maps in preparation include:

1. Tectonic map of North America, scale 1:500,000. 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 is being assembled with the formal and informal cooperation of other national geological surveys in North America and with institutions and individuals. 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; it may also provide indirect leads to the discovery of new metal, fuel, and other economic provinces.
2. Metallogenic map of North America, scale 1:500,000. This map is being compiled under the sponsorship of the Commission for the Geologic Map of the World, now affiliated with both the International Geological Congress and the International Union of Geological Sciences. The North American Metallogenic Map Committee, with P. W. Guild of the U.S. Geological Survey as Chairman, is plotting the mineral deposits of the continent in relation to the geologic and structural features that are believed to control their

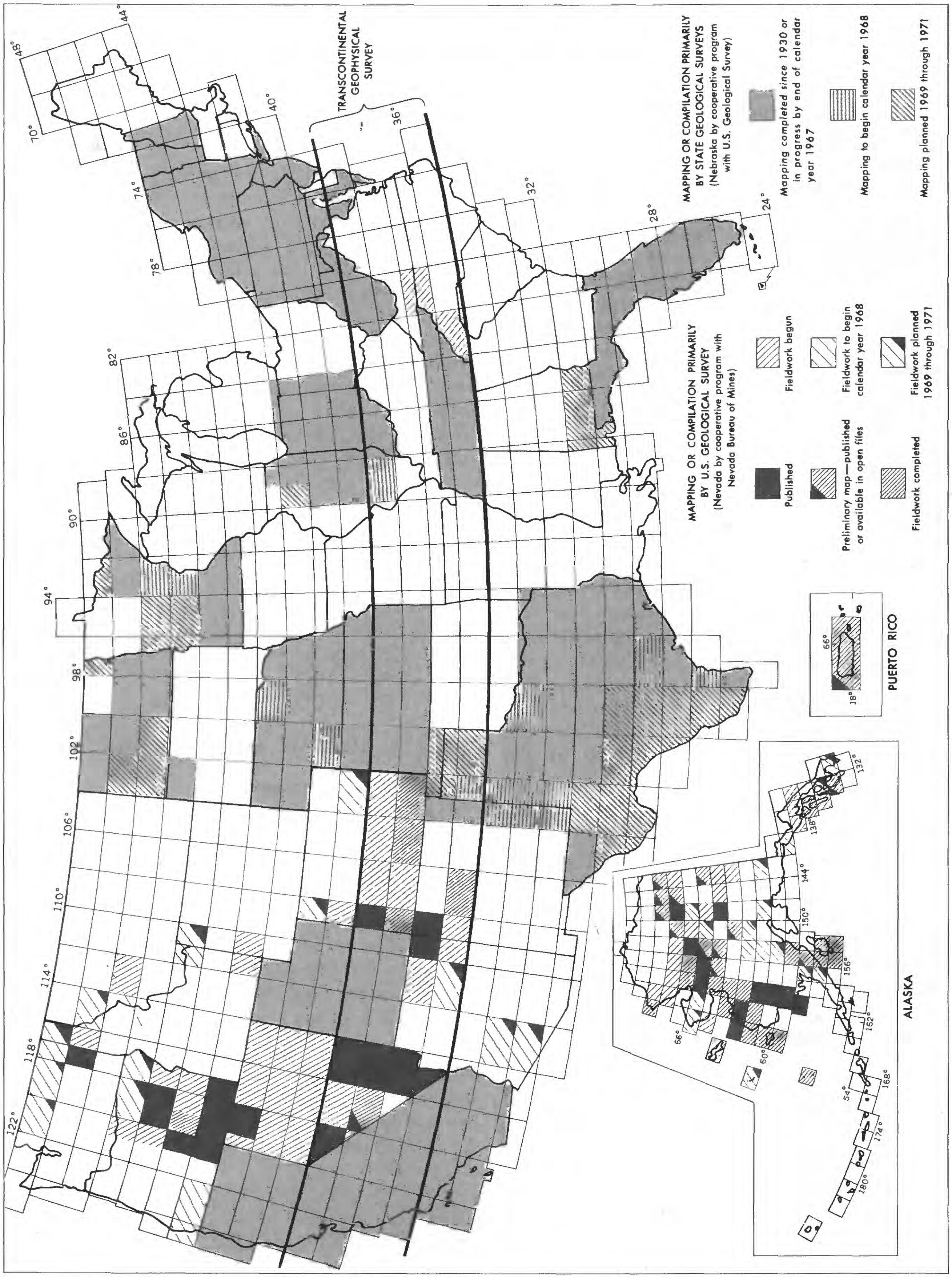

FIGURE 3.—Status of 1:250,000-scale geologic mapping and compilation in the United States as of June 30, 1967.

distribution. As far more data are being assembled than can be portrayed on a single map, the new Geological Survey computer will be used. Magnetic storage and selective retrieval, perhaps combined with automatic plotting, will ultimately facilitate the task of inventorying our mineral resources.

3. Basement-rock map of the United States, scale 1:250,000. This map is sponsored by the Advanced Research Project Agency, Department of Defense, under the direction of W. R. Muehlberger, University of Texas, and R. W. Bayley, U.S. Geological Survey. Compilation has been completed and the map is being prepared for publication. The map will show outcrops of Precambrian and younger basement rocks, the subsurface extension of these as inferred from drill holes, the configuration of the basement-rock surfaces, and the distribution of intrusive rocks of all ages.
4. World map of post-Miocene volcanic landforms. The Geological Survey is cooperating with the International Association of Volcanology (affiliated with the International Union of Geophysics and Geodesy) in the preparation of a distribution map of post-Miocene volcanoes of the World. The map is to be published as a Mercator projection with a scale of 1:20,000,000 at the Equator. The compilation is being done by the World Volcanological Map Committee of IAV (H. Kuno, Chairman) in cooperation with the Commission for the Geological Map of the World of IUGS. R. L. Smith has been appointed Editor for North America.

Paleotectonic maps

The Geological Survey's program for compilation of paleotectonic maps of the conterminous United States for each geologic system is approaching the halfway mark. In 1967, maps and augmenting text for the Permian System were published. Folios for the Jurassic and Triassic Systems were published in 1956 and 1959 respectively, and maps of the Pennsylvanian and Mississippian Systems are in preparation.

Folios for each geologic system contain two sets of maps; a basically factual set at a scale of 1:500,000, and an interpretive set at a scale of 1:10,000,000. The first set includes maps showing the thickness of the system and the thickness and lithofacies of divisions of the system that have been broadly correlated for the country as a whole, and geologic maps show the distribution of rocks underlying and rocks overlying the system. The second set of maps shows reconstructions of the principal tectonic elements that influenced deposition, and identifies some of the environments of deposition and the major direction of transport for sediment.

Permian System

The paleotectonic-map folio of the Permian System has been published in two parts. One, a report by McKee and others,[30] includes two sets of maps and a text which interprets the maps; it also discusses major current problems and significant features of the Permian System. The other report (McKee and others) [31] discusses, region by region the stratigraphy, sources and environments of deposition, and paleotectonic implications of the rocks of the Permian System. In summary, the combined folio shows that during Permian time tectonic activity throughout the United States decreased from a climax attained during the preceding Pennsylvanian Period. Positive areas that were high early in the period were reduced to low relief and, in many places, were buried by sediment; most negative areas and belts, at first moderately deep and sinking, were filled and relatively stable by the end of the period. The transition from Permian to Triassic time took place under a relatively stable tectonic environment; and, in most parts of the western interior, Lower Triassic sediments were deposited on a surface of very low relief.

COASTAL PLAINS

ATLANTIC COASTAL PLAIN

Miocene paleoenvironment study

T. G. Gibson reports that an analysis of Foraminifera from the Miocene deposits of the Atlantic Coastal Plain, combined with a study of the Recent distribution of the same species, has led to the delineation of their paleoenvironments. A synthesis of the paleoenvironment and the stratigraphic framework of the region has permitted a paleogeographic reconstruction of the region during the Miocene. As interpreted, this area was composed of basins separated by intervening highs (positive areas). During the Miocene the basins were differentially mobile, which accounts for the different ages and types of deposits. Primary phosphorite has been found within basins in the more stable areas, chiefly in deposits formed at

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[30] E. D. McKee and others, in press, Paleotectonic maps of the Permian System: U.S. Geol. Survey Misc. Geol. Inv. Map I—450, 164 p., 19 pls., 12 figs., 1 table. [Published Aug. 1967]

[31] E. D. McKee and others, in press, Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Survey Prof. Paper 515, 270 p., 6 pls., 84 figs., 5 tables. [Published Sept. 1967]

depths of 100 to 200 m (the outer shelf) in these basins where there was a mixing of different water masses. Secondary phosphorite, of considerably larger grain size, is found either on the up- or down-basin side, depending upon the direction of the associated transgression or regression.

Biometric analysis of Miocene faunas

The study of mollusks from the Miocene deposits of the Atlantic Coastal Plain by T. G. Gibson has led to a vertical zonation of the deposits by use of biometric analysis of morphologic trends in several genera. Several of the groups are found in various environments, and thus correlation across different lithofacies is possible. By this means, small widely separated outcrops have been fitted into a stratigraphic and structural framework. For example, in North Carolina it has been shown that the commercial phosphorite deposit is composed of phosphatic material of two Miocene ages: a primary one of Calvert age and a secondary deposit of Yorktown age concentrated from the erosion of the primary deposit.

Glauconite dates of coastal-plain formations in New Jersey

A suite of 13 glauconite concentrates from the coastal-plain formations of New Jersey, submitted by J. P. Owens, has been dated by K-Ar isotopic analyses. Seven formations that range in age from Late Cretaceous (Campanian) through early Tertiary (Claiborne) were assembled. Reasonable ages by these analyses were obtained for 9 of the 13 samples as confirmed by their included faunas. Two of the four "unreasonable" ages could be explained because the very low K_2O values of the glauconite indicated incomplete glauconitization. The cause of the other two anomalous ages is not completely understood at this time and is being reexamined.

On the basis of the reasonable ages, massive glauconite formation occurred in New Jersey for a period of about 23.5 m.y.: The Campanian began about 77 m.y. ago and the Claiborne about 53.6 m.y. ago.

Fossiliferous beds along Chesapeake and Delaware Canal, Del.

L. C. Conant observed that shell beds in the Upper Cretaceous Laurel Sand (*Exogyra cancellata* Zone) and Marshalltown Formation (*Exogyra ponderosa* Zone) were being exposed during the widening of the Chesapeake and Delaware Canal at St. Georges, and extensive collections were made from both beds. Although these fossiliferous beds have been reported by other investigators, the fossils obtained from both beds were in an exceptionally fine state of preservation and are currently being examined by the Geological Survey and the National Museum.

Basement high in northern Delaware

Recent mapping in the Betterton area of northeastern Maryland by J. P. Minard has shown that there is considerably less glauconite in the marine Upper Cretaceous formations than in beds of comparable age in New Jersey. The low glauconite content and the decrease in thickness of the whole section, as well as the increase in coarse clastics, suggest deposition on the flanks of a basement high in northern Delaware. This confirms the earlier observation by Clark and others [32] for a high in this general region.

Vertical displacement in southern Atlantic Coastal Plain

S. K. Herrick reports that data from deep wells suggest vertical displacement of some of the coastal-plain formations in the region referred to as the "Suwanee Strait." The affected area extends from Effingham and Chatham Counties in South Carolina across Georgia and into Florida in the vicinity of Decatur and Thomas Counties. The structural displacement seems confined to the beds of early Miocene, Oligocene, and late Eocene (Jackson) age. The causes of the displacement are not yet fully known but may be due to tectonic movements (faulting), ground-water solution (subsurface karst topography), and marine deposition, all of which may have occurred from Oligocene through early Miocene time. Wherever these displaced beds have been noted, particularly in southwest Georgia, quantitative and qualitative ground-water problems exist.

Reevaluation of Oligocene-Eocene sequence in southwestern Georgia

A study of the sediments from a deep well at Cairo by C. W. Sever and S. M. Herrick (p. B50–B53) has necessitated a revision of the Oligocene-Eocene sequence in that area. On the basis of a study of the Foraminifera present, the Marianna Limestone (middle Oligocene) was found to be present in this area. Recognition of this Oligocene unit causes the reassignment of part of the overlying dolomitic beds from the Ocala Limestone (Eocene) to the Byram Formation (middle Oligocene). An Oligocene sequence which aggregates about 500 feet is therefore present in Georgia.

The economic significance of these findings is that the inferior water previously thought to be contained in the Ocala is now known to be in the Byram.

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[32] W. B. Clark, A. B. Bibbins, and E. W. Berry, 1911, The Lower Cretaceous deposits of Maryland: Maryland Geol. Survey, Lower Cretaceous, p. 23–98.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT

Eocene clay deposits in Jackson Purchase region, western Kentucky

Stratigraphic investigations in the Jackson Purchase region by W. W. Olive and W. I. Finch (r2108) combined with information from palynological studies by R. H. Tschudy and X-ray analyses by H. A. Tourtelot and R. P. Christian, reveal that clay deposits of the Wilcox and Claiborne Formations of early and middle Eocene ages contain, on the average, 15 to 25 percent more kaolinite than clay deposits in the Jackson Formation of late Eocene age. Montmorillonite, a relatively rare constituent of clay deposits in the Wilcox and Claiborne Formations, is present generally in amounts exceeding 10 percent in most clay deposits of the Jackson.

Age of Ohio River course below Paducah, Ky.

Fossil wood collected by W. W. Olive from beneath 28 feet of Ohio River alluvium about 14 miles downstream from Paducah is 6,370 ±250 years old according to carbon-14 dating by Meyer Rubin. A previous carbon-14 date of 21,080 ±400 years was determined for shell material deposited in Lake Paducah (W. W. Olive, r0260), which drained northward into the Ohio River. During the time of Lake Paducah, the Ohio River occupied the Cache River valley in southern Illinois. The radiocarbon dates thus indicate that the Ohio was established in its present course below Paducah between times indicated by the two dates, during Wisconsin time.

Owl Creek Formation of Late Cretaceous age in western Tennessee

Mapping in western Tennessee by W. S. Parks and D. L. Brown reveals that the Owl Creek Formation of Late Cretaceous age near the Mississippi-Tennessee State line is composed of about 30 feet of calcareous sand and clay that locally contain abundant fossils. A marine depositional environment is indicated. The unit thins northward, and evidence of marine environment diminishes. In northwestern McNairy County the Owl Creek consists of about 15 feet of nonfossiliferous sand and clay which locally contain sparse glauconite and fossil animal borings. Northward, beds equivalent in age to the Owl Creek so closely resemble the overlying Clayton Formation of Paleocene age that the systemic boundary between the two units cannot be distinguished in the field.

Revision of Upper Jurassic stratigraphic terminology

On the basis of subsurface studies in the northern Gulf coastal areas of Texas, Arkansas, and Louisiana, K. A. Dickinson proposes a revision in nomenclature of the stratigraphic units of Late Jurassic age. The studies show that the downdip equivalents of the Buckner and the upper part of the Smackover Formations are largely included in the Bossier Formation, and that in downdip areas the Bossier lies directly on the lower part of the Smackover Formation. On the basis of these and other findings, the Bossier Formation is redefined to include all rocks above the Smackover Formation and below the Schuler Formation in downdip areas in the north Louisiana basin, and the Schuler is redefined in updip areas to include all the Upper Jurassic rocks above the Buckner Formation. Under the revision proposed by Dickinson, rocks which were formerly included in the Buckner and Schuler Formations and later assigned to the Haynesville Formation are reassigned to the Buckner and Schuler.

NEW ENGLAND AND EASTERN NEW YORK

MAINE

Upper St. John basin studied

Reconnaissance of the Upper St. John River basin and the northwest side of the Allagash River basin in northwestern Maine by E. L. Boudette and others (r2085) has shown the region to be underlain by low-grade regionally metamorphosed sedimentary and volcanic rocks and a single small granitic stock. At least 10 mappable stratigraphic units are present; they trend generally northeasterly. Slate, graywacke, and arkose comprise the largest volume of rock. Polymictic conglomerate, limestone, felsite, quartz-pebble conglomerate and orthoquartzite, and greenstone are locally important as distinctive marker units and possible sources of construction materials near the sites of planned structures for the proposed Dickey–Lincoln School hydroelectric development. The Priestly Lake lowland is underlain by quartz monzonite surrounded by hornfels. Rocks in the southwestern half of the area seem to form a southeast-facing homoclinal sequence. Apparent displacement of units in the northwestern part of the area may result from folds or faults or both. Six new fossil localities indicate that the rocks range in age from Middle Ordovician or older to Early Devonian.

Serpentinites and structure in west-central Maine

A stratiform serpentinite pluton, mapped in the Chain Lakes quadrangle by E. L. Boudette, separates metamorphic rocks of chlorite grade on the south from rocks of sillimanite grade (or higher) on the north. The apparent juxtaposition of widely different metamorphic grades suggests either that the units are not, as once thought, correlative, or that they are separated by a large fault.

A narrow anticlinorium of pre-Silurian(?) rocks has been mapped by D. S. Harwood in the adjacent Arnold Pond quadrangle. A serpentinite body containing slip-fiber and small amounts of short, cross-fiber asbestos is enclosed within these rocks.

Graptolites in Maine support Middle Ordovician age of Partridge Formation

A graptolite assemblage of late Middle Ordovician age from black slate in the Cupsuptic quadrangle of west-central Maine has been described by D. S. Harwood and W. B. N. Berry (p. D16–D23). The same assemblage occurs in parts of the Beauceville Formation (Quebec), Normanskill Shale (New York), and various units in northwestern Maine. The slate is correlated with the Partridge Formation in New Hampshire on the basis of lithographic similarity and stratigraphic position, thus supporting the Middle Ordovician age previously suggested for the Partridge. The black slate is overlain by fossiliferous rocks of Early to Late Silurian age.

Ferrous metals in west-central Maine

Several metal-bearing localities have been discovered by E. L. Boudette in mapping the Kennebago Lake and Chain Lakes quadrangles. A nearly continuous belt of iron-formation within the graywacke-volcanic rock sequence may be more than 50 feet thick in places. This association is remarkably similar to that at Brunswick Mines in Bathurst, New Brunswick; however, no sulfide mineralization is now known to be associated with the iron-formation in Maine.

As much as 1,000 ppm Ni and 1,500 ppm Cr occur in altered volcanic rock in west-northwest-trending fault zones. Serpentinite-carbonate bodies occur along the same structures, and the carbonate rock contains as much as 2,000 ppm Cr. The fault zones appear to have been conduits for mineralizing solutions associated with the serpentinization process. One serpentinite body can be traced into anorthosite, but most of the known serpentinite-carbonate bodies are enclosed by greenstone.

Gabbroic sills related to the Stratton pluton have extensively intruded Silurian-Devonian rocks. The sills define both broad open folds and locally sharp flexures broken by thrust faults. A contact metamorphic aureole around the pluton is displaced by thrusting. Anomalous bismuth occurs in one of the thrust-fault zones.

Mercury found in sulfides in west-central Maine

An anomalous mercury value of 6,000 ppb was found in a sample of massive pyrite-chalcopyrite collected by D. S. Harwood from the Rump Pond–Trasher Peaks area in the Second Lake and Cupsuptic quadrangles. The sulfides occur as scattered veinlets in a mineralized zone a few feet wide in schistose feldspathic graywacke and felsite. The anomalous mercury should be postmetamorphic (Acadian) in age because of its high volatility; the presence of 450 to 2,200 ppb Hg in sulfides on the east border fault of the Triassic basin in Connecticut suggests a post-Triassic age. For comparison, sulfide specimens from 10 other deposits in Maine and New Hampshire, submitted for analysis by L. R. Page, range from 20 to 3,400 ppb Hg.

MASSACHUSETTS

Tectonics of eastern Massachusetts

Eastern Massachusetts consists of a series of overthrust fault plates that strike northeastward and moved toward the east, according to K. G. Bell. The major faults have vertical displacements of thousands of feet and horizontal movement on the order of miles. Preliminary division of igneous rocks into magma series indicates that different series were emplaced during pre-Acadian, Acadian, and post-Acadian times.

Age and weathering of Blue Hill Granite Porphyry

Mapping in the Blue Hills quadrangle, south of Boston, by N. E. Chute reveals that the Blue Hill Granite Porphyry, formerly considered to be a chilled marginal phase of the Quincy Granite, is a younger intrusive. The granite has a thin porphyritic border facies that is unlike the granite porphyry. The xenoliths in the two rocks are dissimilar.

The granite porphyry was deeply weathered prior to deposition of the overlying Pondville Conglomerate of Pennsylvanian age. This Paleozoic weathering is usually well exposed below the conglomerate in the roadcuts at the intersection of Routes 28 and 128 on the south side of the Blue Hills. An indurated massive red soil zone about 9 feet thick grades downward into spheroidally weathered porphyry about 30 feet thick, which is separated from unweathered porphyry by about 40 feet of partly weathered rock.

Hardwick Granite correlated with New Hampshire rocks

An area once mapped by B. K. Emerson as Hardwick Granite (upper Paleozoic) near Athol, north-central Massachusetts, is a complex of several igneous rocks with some intermixed schists and gneisses of the Littleton Formation (Devonian), according to A. L. Mook. Three members of the syntectonic New Hampshire Plutonic Series are exposed, and the Hardwick Granite is probably a late differentiate of that series.

Stratigraphy in Berkshire Highlands

Mapping by N. L. Hatch, Jr., in northwestern Massachusetts has increased the known extent of the Hoosac, Rowe, Moretown, Hawley, and Goshen Formations. These units have now been traced south from the Vermont State line for 25 miles by detailed mapping and for nearly 15 miles more by reconnaissance. All formations show considerable thickening and thinning, and lateral facies changes are numerous. The Hoosac and Moretown Formations show the least lateral lithologic variation.

The Middle Ordovician Berkshire Schist is unconformable on Lower Ordovician to Precambrian rocks in the Hoosac nappe in the Windsor quadrangle of northwestern Massachusetts, which was mapped by S. A. Norton. After the formation of the nappe the rocks were refolded at least once, cut by high-angle and possibly low-angle thrust faulting, and affected by widespread retrograde metamorphism.

Mapping in the West Granville quadrangle on the Connecticut State line in southwestern Massachusetts by R. W. Schnabel has shown the continuity of the Hoosac and Moretown Formations into this quadrangle. These high-grade metamorphic rocks are intruded by a 3- by ½-mile body of postmetamorphic diorite and pegmatite.

Aeromagnetic and aeroradioactivity surveys

Approximately 4,500 square miles of Massachusetts has been covered by aeromagnetic and aeroradioactivity surveys by the U.S. Geological Survey in cooperation with the State. R. W. Bromery reports that aeromagnetic-anomaly patterns delineate exposed and buried magnetic rock units and contribute significantly to the geologic-mapping program in the area. These data have provided information on geologic structures and lithologies and have indicated areas of mineralization that may be of economic importance. Of particular significance is a current study of the pronounced positive magnetic anomalies associated with three gneiss domes in the vicinity of Shelburne Falls, Goshen, and Woronoco. Analyses of these anomalies indicate 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. The aeroradioactivity data provide useful information that correlate with the magnetic data and that, in addition, delineate the nonmagnetic rock units and those lithologies that do not show distinctive magnetic-anomaly patterns. Similar results have been obtained in other areas in the eastern United States.

Glacial deposits of Cape Cod

Compilation by R. N. Oldale of recent mapping on Cape Cod establishes a succession of drift units, defined by altitude, topographic form, lithology, and texture. Three of these units are new: the Nauset Heights, younger Wellfleet plain, and Highland plain deposits. The probable succession from oldest to youngest is: (1) older drift at Chatham and near Nantucket Sound, (2) Buzzards Bay moraine, (3) Sandwich moraine, (4) outwash south of Sandwich moraine, (5) Nauset Heights deposits, (6) older Wellfleet plain deposits, (7) younger Wellfleet plain deposits, (8) Highland plain deposits, (9) Truro plain deposits, (10) Eastham plain deposits. All of this drift was deposited during the retreat of the last ice sheet, probably between 14,000 and 15,000 years ago.

Erosional furrows in outwash of southeastern Massachusetts

Erosional furrows that trend at angles of 15° to 40° west of the present southward slopes of outwash plains have been described by Carl Koteff and J. P. Schafer from four areas of proglacial outwash in southeastern Massachusetts. The furrows are believed to have been eroded in late-glacial time by local runoff and emerging ground water, probably under permafrost conditions. There is no satisfactory explanation for the anomalous directions of the furrows, but in each area the furrows are parallel to the adjacent front of the Buzzards Bay lobe of the ice sheet.

Large ice-dammed lake in western Massachusetts

Reconnaissance studies by G. W. Holmes in the Hoosic and Housatonic valleys in western Massachusetts indicate that a single glacial lake extended at least 50 miles from the Vermont border to the Connecticut border. The most prominent shorelines are in the Hoosic drainage to the north, at an altitude of about 1,130 feet, and the outlet was below 880 feet. Preliminary measurements of shore features suggest that the amount of isostatic tilt is between 4 and 5 feet per mile.

CONNECTICUT

Structure and stratigraphy of eastern Connecticut

A northeast-trending fault mapped in the Eastford quadrangle by M. H. Pease, Jr., separates two sequences of rock. Rocks southeast of the fault correlate with previously mapped units of eastern Connecticut, and rocks northwest of the fault are continuous with strata in south-central Massachusetts, but correlation across the fault is not certain. Metasedimentary rocks of the lower Paleozoic Brimfield Schist to the west in the adjoining Westford quadrangle are assigned by Pease and J. D. Peper to two major units. An eastern (lower) unit of dominantly gray schist with minor calc-silicate rock, amphibolite, and rusty schist, and a western (upper) unit of rusty-weathering schist are separated by a belt of interbedded schist and calc-silicate rock.

The major thrust fault of the eastern Danielson and Plainfield quadrangles has been traced by H. R. Dixon south to the area of the upper Paleozoic Preston Gabbro. The fault splits into two branches, which pass above and beneath the gabbro; the major displacement is among the lower branch. Northward, the fault extends into the western part of the East Killingly quadrangle, according to G. E. Moore, Jr.

Mercury anomalies near Middletown

Trace-element concentrations of mercury (450 and 2,200 ppb) found by G. P. Eaton in a mineralized zone in the Brimfield Schist, east of Middletown in central Connecticut, are as great as those found in mercury halos associated with exploitable mercury ore deposits in the U.S.S.R.

Indicator fans in southwestern Connecticut

A broad indicator fan derived from Triassic basalt of the Pomperaug Valley has been mapped in the Woodbury and Southbury quadrangles by Fred Pessl, Jr. The axis of the fan trends S. 20° E. A distinctive coarse kyanite schist in the adjacent Newtown quadrangle is the source of a boulder train that has been traced for about 2 miles; the axis of this train trends S. 33° E.

Glacial geology in western Connecticut

According to H. E. Malde, the Norwalk Islands, a mile off the Connecticut shore, are most likely remnants of a moraine that may represent a significant pause in the retreat of ice northward from Long Island.

A north-trending drift border is inferred by R. B. Colton near the west edge of the Collinsville quadrangle on the basis of contrasting directions of drumlins and striations, and glacial-lake phenomena. This is believed to mark the west border of an ice lobe lying in the Connecticut Valley.

Altitudes of glacial-lake deltas in the Pomperaug Valley, mapped by Fred Pessl, Jr., indicate postglacial isostatic tilt of about 5 feet per mile northward.

Ice-push ridges on Gardner Lake shore

A modern ice-push ridge behind the beach on the north shore of Gardner Lake, near Norwich in eastern Connecticut, has been studied by Fred Pessl, Jr. The ridge is as much as 5 feet high and 10 feet wide. In early 1967, the positions of survey stakes on lake ice were periodically determined, and air and ice temperatures and solar radiation were measured. The results support the hypothesis of thermal expansion as the principal cause of ice push, rather than wind.

EASTERN NEW YORK AND WESTERN NEW ENGLAND

Structure of Taconic allochthon

Continued study of the Taconic allochthon in western New England and eastern New York by E-an Zen shows that it consists of 6 or 7 slices. The younger the age of emplacement of the slice, the older its stratigraphic section, so that there is almost no stratigraphic overlap between the oldest and the youngest slices. This fact considerably ameliorates the room problem for the allochthon. The oldest slice was emplaced as soft rocks in a marine environment; the youngest slice, composed of older rocks and probably emplaced subaerially, behaved more like competent rocks. An extensive area of rocks at the very north end of the allochthon in western Vermont, previously interpreted as part of a nappe, is now believed to be a body of wildflysch-type conglomerate. Deformed fragments of allochthonous rocks, from a few millimeters to a few hundred meters across, lie in a matrix of Middle Ordovician black slate.

Detailed mapping just east of the Taconic Mountains in southwestern Massachusetts by N. M. Ratcliffe has shown the presence of two westward thrusts. On one, the gneisses of the Berkshire Mountains lie on Paleozoic rocks. Because the rocks of the thrust sheets are much less deformed than those below, the thrusts may be Devonian (Acadian) rather than Ordovician (Taconic) in age.

Connecticut Valley glacial-lake history

The history of glacial Lake Hitchcock has been clarified by work in the Connecticut Valley of Connecticut and Massachusetts by J. H. Hartshorn and others. Early, short-lived lakes formed in Connecticut behind the deltaic dam north of Middletown, and north of a divide at New Britain. The main lake level was controlled by a bedrock-floored spillway cut in the New Britain divide, and the lake persisted at this level at least during the retreat of the ice sheet across Massachusetts. The lake levels are defined principally by deltas and beaches. In the valley, the retreating margin of the ice sheet formed a lobe that stood south of the margin on the adjacent uplands.

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Postglacial tilting in southern New England

Altitudes of glacial lakes, based on topset-foreset contacts in deltas, have been determined by Carl Koteff for the Clinton and Concord areas of northeastern Massachusetts, the Merrimack Valley of southern New Hampshire, and the Connecticut Valley of western Connecticut and Massachusetts. The planes of the water levels of these former lakes form parallel straight-line profiles, tilted upward to the north between 4 and 4½ feet per mile, and covering an area that extends 100 miles in a north-trending direction. Therefore there are no hinge lines in the profile area, and the tilting occurred after rather than during the time of existence of the lakes.

Retreat of last ice sheet in New England

Radiocarbon dates and other data compiled by J. P. Schafer provide a rough outline of the retreat of the last ice sheet. The glacier reached its maximum extent about 19,000 to 20,000 years ago. The beginning of retreat from Martha's Vineyard may be recorded by a date of 15,300±800 years. The Boston basin was uncovered before the deposition of clay about 14,000 years ago, and then the brief Cambridge readvance and the possibly correlative Middletown readvance of central Connecticut occurred. The succeeding retreat through New Hampshire and Vermont into the St. Lawrence Valley had occurred by about 12,700 years ago. Rates of retreat seem to have been about 400 feet per year in southern New England and 1,500 feet per year in northern New England.

Fault zone in northwest Adirondack Mountains

A major system of faults along the Oswegatchie River, in the Richville and Bigelow quadrangles, northwest New York, has been recognized by H. M. Bannerman. The faults separate tightly folded metasedimentary and metavolcanic gneisses and schists to the east from less deformed marble, quartzite, amphibolite, and granitic gneisses to the west. The main fault is a low-angle west-dipping right-lateral thrust. The faulting affects all the Precambrian rocks, but is older than the Potsdam Sandstone of Late Cambrian age. The sandstone unconformably overlies the Precambrian complex, and fills solution cavities in carbonate rocks.

Boron-rich deposits in metasedimentary rocks of northwest Adirondack Mountains

H. M. Bannerman has also mapped extensive bodies of boron-rich material in the metasedimentary rocks of the northwest Adirondacks that are described above. The boron occurs mainly in dravite, a sodium-magnesium tourmaline, that is generally concentrated in fine-grained quartz-microcline gneiss and associated quartzite and marble. Boron-rich bodies reach a maximum size of at least 150 feet by 2,000 feet. Maximum concentrations of at least 25 percent dravite occur in some deposits. The dravite developed early in the recrystallization process; the boron was introduced probably hydrothermally, during the diagenesis of the sediments.

Magnetization of anorthosite in Adirondack Mountains

Directions and intensities of remanent magnetization of more than 100 specimens of anorthosite, gabbroic anorthosite, and anorthositic gabbro from the Adirondacks have been measured by M. E. Beck, Jr. Only the more mafic specimens have a significant degree of magnetic stability, and it is concluded that anorthositic rocks are not well suited to measurements of rock magnetism.

Downwasting of glacial ice southeast of Catskill Mountains

M. H. Frimpter reports that downwasting of the Wisconsin ice sheet in central Ulster County, N.Y., may explain the scarcity of glacial sand and gravel in this area. The narrow valleys of Esopus and Rondout Creeks on the southeastern flank of the Catskill Mountains contain more than 75 feet of clay and silt capped by relatively thin alluvial sand and gravel. The clay and silt are believed to have been deposited in ice-dammed lakes, formed as downwasting gradually uncovered the southeastern flank of the Catskills while ice still persisted in the adjoining lowlands. Moraines previously mapped in the area support the conclusion that the lower elevations were the last areas to be free of ice.

APPALACHIAN REGION

NEW YORK, NEW JERSEY, AND PENNSYLVANIA

Revision of uppermost Silurian and lowermost Devonian stratigraphy

Complex lateral and vertical facies changes involving lagoonal, barrier-beach, biohermal, and shallow- to deep-water neritic lithofacies have been revealed by stratigraphic and micropaleontologic studies of uppermost Silurian and lowermost Devonian strata from Port Jervis, south-central New York, to Bossardsville, northeastern Pennsylvania by A. G. Epstein; by quadrangle mapping in northeasternmost Pennsylvania by J. B. Epstein; and by quadrangle mapping in northwestern New Jersey by W. J. Spink and D. S. Jennings (New Jersey Bureau of Geology). The stratigraphic nomenclature of rock units within this interval has been modified and refined (Epstein and others, r1957).

System of décollements in eastern Pennsylvania

Intensive studies of fold systems and exploration of scanty geophysical data by G. H. Wood, Jr., indicate that a master system of décollements underlies the Pennsylvania Anthracite region at or near the base of the Paleozoic sedimentary sequence. The structural features in the region developed by gravity gliding or thrusting of the upper plate of the system. Movement began during the Taconic orogeny, continued in the Acadian orogeny, and culminated during the Appalachian orogeny. The décollements are believed to be continuous with those now known to underlie the Valley and Ridge and Appalachian Plateaus provinces to the west and southwest.

Investigation of bedding-plane slippage and wedging in the Bloomsburg Red Beds of Silurian age at Lehigh and Delaware Water Gaps, Pa., by J. B. Epstein shows that there has been considerable northwest transport of rocks. At Lehigh Gap the accumulated telescoping is estimated to be at least 10,000 feet and could easily be many miles. The Bloomsburg, and possibly the overlying Poxono Island Formation of White (1882),[33] is therefore interpreted as a major décollement zone separating rocks with differing styles of deformation and amplitudes of folds. Because the detachment zone dips to the northwest and may be rootless, northwest movement into the Appalachian basin may have been primarily by gravitational sliding, although aided by directed tectonic forces. Because fan cleavage in the folds is deformed at slippage planes, the slippage must have occurred after folding. Similar detachment zones may be present in the Marcellus Shale of Devonian age and between the Shawangunk Conglomerate of Silurian age and the Martinsburg Formation of Ordovician age.

Age of cleavage in Martinsburg Formation of Pennsylvania

Structural and sedimentalogical data gathered by J. B. Epstein at and near the contact between the Martinsburg Formation of Ordovician age and the Shawangunk Conglomerate of Silurian age, in easternmost Pennsylvania, indicate that there is an angular unconformity separating the two formations. This unconformity is ascribable to the Taconic orogeny. However, relations between major and minor structures in the Martinsburg and in younger rocks suggest that the pervasive cleavage in the Martinsburg, hitherto generally assigned a Taconic age, is Acadian or Appalachian in age. The degree of deformation during the Taconic orogeny probably was more intense to the southeast.

[33] I. C. White, 1882, The geology of Pike and Monroe Counties: Pennsylvania Geol. Survey, 2nd rept., G–6, p. 1–333.

Nappe underlies Reading Prong and Lehigh Valley, Pa.

Mapping and studies of minor structures by J. M. Aaron in the Nazareth quadrangle, Northampton County, Pa., support the interpretation that the lower Paleozoic and Precambrian rocks of the Lehigh Valley and Reading Prong are underlain by the refolded inverted limb of a large nappe. The rocks have been deformed at least twice, but the chronology of deformation and effects of each deformation are not entirely clear. Petrographic studies indicate that calcite oolites were dolomitized after deformation.

Structurally controlled gaps in eastern Pennsylvania

The conclusion by J. B. Epstein[34] that wind and water gaps are structurally controlled is corroborated by mapping of Little Gap, Lehigh Gap, and Lehigh Furnace Gap in Lehigh, Northampton, and Carbon Counties, Pa. These gaps occur where folds end over short distances, on the limbs of recumbent, nearly isoclinal folds, and where a longitudinal fault emerges from the core of an antiform and has been rotated about a vertical axis during refolding.

Geophysical study of Appalachian flexure

The sense and amount of transcurrent movement which produced the flexure in the Appalachians near the 40th parallel have been inferred by R. W. Bromery from gravity and aeromagnetic data in New Jersey, Pennsylvania, Delaware, and Maryland. Aeromagnetic data indicate that Buckingham Mountain, located in the Triassic basin northeast of Philadelphia, may be structurally and lithologically related to the Pigeon and Hallam Hills anticline 80 miles to the west in the vicinity of York, Pa. Detailed gravity data in New Jersey, Delaware, and Maryland show that a pronounced gravity high extends along the east coast of the United States from northern Vermont to Alabama. This high is offset southwestward from a point just south of the 40th parallel near Camden, N.J., to a point in Baltimore County northwest of Baltimore, Md. The sense of the offset is right lateral and the magnitude of displacement is approximately 80 miles.

Discharge of glacial Lake Sciota, Pennsylvania

Mapping of low-level Wisconsin outwash terraces by J. B. Epstein in eastern Pennsylvania has shown that the early outlet of glacial Lake Scotia, an ice-

[34] J. B. Epstein, 1966, Structural control of wind gaps and water gaps and of stream capture in the Stroudsburg area, Pennsylvania and New Jersey, *in* Geological Survey Research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B80–B86.

defended morainal dammed lake that existed in the Stroudsburg area, was through Lehigh Gap via Buckwha and Aquashicola Creeks and the Lehigh River. A later and lower outlet for the lake was through Delaware Water Gap. Higher level terraces underlain by deeply weathered drift in the Lehigh Valley near Palmerton may be of Illinoian age.

MARYLAND

Linear magnetic anomalies suggest possible major faulting

A striking belt of linear magnetic anomalies ranging from about 1 to 4 miles in width crosses northern Harford County and continues southwestward through Baltimore and Carroll Counties, according to D. L. Southwick and R. W. Bromery. It passes just northwest of the Phoenix gneiss dome and in Harford County goes along the northwest flank of the Peach Bottom syncline; it is on strike with the Cream Valley fault system of Pennsylvania, but actual connection with the Cream Valley system is yet to be proved. The linear anomalies are over a zone of strongly deformed albite-chlorite-muscovite quartz schists within which are numerous elongate pods of sheared ultramafic rock. Minor fold axes in the schist plunge steeply, in places up to 70°. The significance of this zone is not clear at present, but the zone may possibly be a major fault zone.

VIRGINIA, NORTH CAROLINA, TENNESSEE, AND GEORGIA

Fracture traces in Shenandoah Valley, Va.

F. W. Trainer (U.S. Geological Survey) and R. L. Ellison (University of Virginia) (r1516) have noted that only vertical joints in folded carbonate rocks and shale in the Shenandoah Valley appear as fracture traces on aerial photographs. The study methods used have been described by Trainer (p. C184–C188). The vertical joints make up a part of the total joint population. The fracture traces seem to be more abundant in gently dipping strata than in steeply dipping beds, in carbonate rocks than in shale, and in calcium-rich limestone than in dolomite and cherty or shaly carbonate rocks.

Wedging out of Pocahontas Formation in Virginia

Stratigraphic and isopach studies in southwestern Virginia by K. J. Englund delineate a northwestward wedging out of the Pennsylvanian Pocahontas Formation in the subsurface. This trend is approximately normal to the Russel Fork fault and indicates that strike-slip movement is substantially greater than heretofore estimated. Wedging out of the formation is also of economic significance as it limits the northwestward extent of the low-volatile Pocahontas coals, which currently are the objective of deep drilling by mining companies.

Granite pegmatite bodies recognized in Virginia Piedmont

S. K. Neuschel has delineated two granite pegmatite intrusives in the Spotsylvania area of the Virginia Piedmont on the basis of unusual aeroradioactivity highs. The presence of the intrusives was substantiated by field reconnaissance. Neuschel has also found that rocks containing chlorite-magnetite-plagioclase assemblages in this part of the Piedmont produce high magnetic anomalies and can readily be distinguished from rocks containing quartz-plagioclase-muscovite assemblages, which characteristically have lower magnetic values.

Pine Mountain fault system in Virginia, Tennessee, and Georgia

Regional analysis of the Pine Mountain thrust plate by L. D. Harris has suggested that thrust faults and transverse faults form an integrated structural system. Thus, the Pine Mountain thrust fault may be only a part of a more extensive system, which includes the Russell Fork and Jacksboro transverse faults and the Chattanooga thrust fault. The surface trace of this system extends from Virginia to Georgia, a distance of 300 miles. Drilling northeast of the Pine Mountain plate has established the presence in the subsurface of the Pine Mountain thrust fault; however, drilling has not as yet delineated the regional extent of the subsurface thrusting. The Pine Mountain fault system may link with the extensive subsurface thrust system described by Gwinn[35] in West Virginia, Virginia, Maryland, and Pennsylvania.

Ocoee Series and Chilhowee Group in North Carolina and Tennessee

A continuous stratigraphic sequence from the upper part of the Ocoee Series (upper Precambrian) into the Chilhowee Group (Cambrian, at least in part) northeast of the Great Smoky Mountains in eastern Tennessee has been studied by J. B. Hadley and A. E. Nelson. This study shows that the Walden Creek Group of the Ocoee is much thicker and that rocks of the lower part of the Chilhowee are thinner than previously described. The Walden Creek overlies the Snowbird Group in this area but is absent above the Snowbird in thrust sheets that have moved northward;

[35] V. E. Gwinn, 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge provinces of the Central Appalachians: Geol. Soc. America Bull., v. 75, no. 9, p. 863–900.

this suggests that rocks of the Walden Creek Group were removed by erosion in Ocoee time or were not deposited in the southern part of the Ocoee sedimentary basin.

In Madison and Buncombe Counties, N.C., Hadley and Nelson found that rocks of the Ocoee Series extend 30 or more miles east of their previously known limit and underlie the Black Mountains and adjacent areas to the south and southwest. In these areas the Ocoee rocks are largely thick- to medium-bedded metasandstone and metapelitic rocks with arkosic conglomerate resembling rocks of the Great Smoky Group in areas farther west. Also in these areas the Ocoee rocks lie on older Precambrian gneisses, are metamorphosed to sillimanite grade, and are invaded by various granitic rocks. Mafic rocks sparsely intercalated with the metasedimentary rocks of this area are intrusive lenses and sheets of metagabbro and peridotite.

Blue Ridge thrust sheet in southern Appalachians

D. W. Rankin's work on the Blue Ridge thrust sheet, composed of Precambrian rocks, in the Winston-Salem quadrangle (scale 1:250,000), northwest North Carolina and southwest Virginia, has shown that older Precambrian granitic gneisses (equivalent to rocks dated at 1,050 m.y.) are exposed in an allochthonous anticline northeast of the Grandfather Mountain window. The older Precambrian rocks are flanked by upper Precambrian rhyolite and very coarse conglomerate of the Mount Rogers Volcanic Group on the northwest side of the anticline and by a thick sequence of interlayered amphibolite (metabasalt and metadiabase) and mica gneiss and schist (metamorphosed graywacke and shale) of late Precambrian age on the southeast side. The upper Precambrian rocks probably correlate with the upper Precambrian Ocoee Series to the southwest and with the Lynchburg Formation to the northeast. Metamorphic grade in the Blue Ridge thrust sheet increases steadily to the southeast from chlorite-zone assemblages to kyanite-staurolite assemblages on the south flank of the anticline.

Brevard zone widens northeast of North Wilkesboro, N.C.

G. H. Espenshade has traced the upper Precambrian Lynchburg-type gneiss eastward to the border of the Brevard zone in the western Piedmont. The Brevard zone is a narrow linear southwest-trending fault zone more than 300 miles long. The zone includes several parallel faults near North Wilkesboro, and 40 miles northeast of North Wilkesboro it widens to nearly 12 miles. Two distinct groups of rocks occur within this widening belt. Along the southeastern side is a mixed assemblage of lenticular gneisses and schists probably representing several stratigraphic units juxtaposed by faulting; on the northwest is a belt of phyllite and fine granetiferous mica schist containing thin beds of graphitic schist, graywacke, and fine conglomerate. The rocks in this northwest belt apparently extend 150 miles northeastward to the James River synclinorium near Lynchburg, Va., and may be equivalent to the Evington Group. This northwestern sequence, therefore, is possibly part of a synclinorium of lower Paleozoic(?) eugeosynclinal rocks that border the Blue Ridge–Catoctin Mountain anticlinorium from Virginia to North Carolina, where the synclinorium passes into the Brevard fault zone.

Espenshade has found that the inner Piedmont area southeast of the two groups of Brevard-zone rocks consists of augen gneiss, biotite gneiss, and sillimanite schist intruded by syntectonic granodiorite to quartz monzonite plutons.

Age of massive cupriferous pyrrhotite deposits in North Carolina and Virginia

Cupriferous pyrrhotite deposits at Ore Knob, N.C., and Gossan Lead and Toncrae, Va., in the Winston-Salem quadrangle (scale 1:250,000), are podlike masses elongated parallel to Paleozoic structures but are in upper Precambrian Lynchburg-type gneiss. D. W. Rankin and G. H. Espenshade conclude that these massive sulfide deposits are either Paleozoic in age or are Precambrian deposits and that they were metamorphosed in Paleozoic time.

EASTERN PLATEAUS

NEW YORK, PENNSYLVANIA, AND OHIO

Revised Devonian correlations

Work by W. A. Oliver, Jr., Wallace deWitt, Jr., J. M. Dennison (University of Tennessee), D. M. Hoskins (Pennsylvania Geological Survey), and J. W. Huddle has resulted in numerous revisions of Devonian correlations and the age assignments of formations. A thick sequence of limestone in the subsurface of northwestern Pennsylvania previously identified as the Tully Limestone is now thought by deWitt to be an equivalent of the Centerfield Limestone Member of the Ludlowville Shale. Limestone of Helderberg age has been recognized by Oliver and deWitt in the subsurface of Lake and Geauga Counties, Ohio.

Orientation of carbonate concretions in Upper Devonian strata in New York

The long axes of argillaceous limestone concretions in the lower part of Upper Devonian marine strata in western New York are reported by G. W. Colton (p. B57–B59) to be preferentially oriented to the northeast. The alinement probably is parallel with the primary depositional fabric of the enclosing beds and, thus, with movement of marine currents.

Basic dike along northwest-trending strike-slip fault in Pennsylvania

Surface and subsurface studies by J. B. Roen in the vicinity of Stringtown and Edenborn, Greene and Fayette Counties, have shown that an ultramafic dike intruded nearly horizontal beds along a strike-slip fault zone. Displacement is probably small and is left lateral. The fault zone, not previously reported, is at least 5 miles long.

KENTUCKY

Subsurface extension of No. 4 coal bed in western Kentucky

A coal bed known locally in the southwestern part of the western Kentucky coal basin as the Dawson Springs No. 6 has been designated the No. 4 coal bed by T. M. Kehn and others (p. C160–C164). It was recognized from study of electric logs of oil and gas test holes to be about 200 feet below the No. 6 coal bed, which is in the Pennsylvanian Carbondale Formation and present throughout most of the coal basin. The No. 4 has been mined along the edge of the basin, and minable reserves of it may occur in adjacent localities deeper within the basin. Most coal test holes in those areas have not been drilled deeper than the No. 6, seemingly because the No. 4 where mined at the edge of the basin was thought to be the same as the No. 6 coal bed.

Northwest-trending faults in central Blue Grass region

Geologic mapping by E. R. Cressman, D. F. B. Black, W. C. MacQuown, Jr., and R. D. Miller of Middle Ordovician rocks on Jessamine Dome in the central Blue Grass region (Jessamine and surrounding counties) has located many northwest-trending normal faults and grabens. Vertical displacement along most faults is less than 50 feet. Down-dropped blocks of the Drakes Formation of Late Ordovician age along about a dozen faults, however, indicate vertical displacements of 500 to 750 feet for those faults. In the Salvisa quadrangle, the northwest-striking faults and grabens occur en echelon in a north-northwest-trending zone, suggesting a relationship to left-lateral strike-slip faulting at depth.

Previously described major faults in the area are part of the Kentucky River and West Hickman fault zones, which trend eastward and northeastward, respectively. Few northwest-trending faults in the central Blue Glass area have been recognized until recently (G. C. Simmons, r0114).

Thinning of Lexington Limestone northward from Lexington

Information obtained by D. F. B. Black, E. R. Cressman, and J. P. Ford from surface sections and cores in north-central Kentucky demonstrates that the Lexington Limestone, predominantly fossiliferous limestone and calcarenite of Middle Ordovician age, thins from 310 feet near Lexington northward in 45 miles to 170 feet at Falmouth, Ky. The thinning results from intertonguing of the Lexington with limestone and shale similar to the Point Pleasant Formation of the Ohio River valley near Cincinnati. Black and others [36] have shown that the Lexington Limestone thins southward from Lexington by intertonguing of its upper part with interbedded shale and limestone of the Clays Ferry Formation. Thus, the Lexington Limestone is thickest in a zone that trends eastward through Lexington and crosses the axis of the Cincinnati arch perpendicularly.

Devonian-Mississippian boundary in Kentucky

Conodont studies by J. W. Huddle of collections from low in the Borden Formation at many localities in south-central Kentucky highlight some interesting problems regarding the Devonian-Mississippian boundary. The base of the Nancy Member in the vicinity of Berea is of cuII β age, equivalent to the lower part of the Burlington Limestone. Farther south, near Somerset, the basal Nancy is of latest Devonian (to VI) age, equivalent to the Louisiana Limestone and part of the New Albany Shale. In geographically intermediate areas, the base of the Borden contains conodonts of cuI age, approximately equivalent to the Hannibal Shale. Progressive northward overlap of beds referred to the Borden Formation is indicated.

Lower Pennsylvanian of Big Stone Gap district, Kentucky-Virginia

Study by Mackenzie Gordon, Jr., of invertebrate fossils from the Wise Formation collected by R. L. Miller, together with earlier studies of these faunas in eastern Kentucky, indicates that the Kendrick Shale of Jillson (1919) [37] is definitely of Morrow age and can be correlated with some part of the Bloyd Shale that overlies the Baldwin coal bed in Arkansas. The Magoffin Beds of Morse (1931) [38], higher in the section,

[36] D. F. B. Black, E. R. Cressman, and W. C. MacQuown, Jr., 1965, The Lexington Limestone (Middle Ordovician) of central Kentucky: U.S. Geol. Survey Bull. 1224–C, p. C8.

[37] W. R. Jillson, 1919, The Kendrick Shale—a new calcareous fossil horizon in the Coal Measures of eastern Kentucky: Kentucky Dept. Geology and Forestry, Mineral and Forest Resources of Kentucky, ser. 5, v. 1, no. 2, p. 96–104.

[38] W. C. Morse, 1931, The Pennsylvanian invertebrate fauna of Kentucky, *in* Paleontology of Kentucky: Kentucky Geol. Survey, ser. 6, v. 36, p. 293–348.

clearly can be placed near the Morrow-Atoka boundary. Gordon suggests that the Magoffin Beds may also be of Morrow age.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY

MICHIGAN

Dead River basin stratigraphy

The part of the Dead River basin in the central area of the Negaunee 7½-minute quadrangle in the Marquette iron-bearing district of northern Michigan is described by W. P. Puffet as being underlain by three major rock units. Metasedimentary rocks in the north and south parts of the basin are separated by a belt of sheared metavolcanic rocks that are probably the western extension of sericite-chlorite slate and schist mapped with the Mona Schist of early Precambrian age in the Marquette quadrangle, about 6 miles to the east. The northern unit is probably of early middle Precambrian or older age and in part is of glacial origin. The southern unit is assigned to the Michigamme Slate of the Animikie Series of middle Precambrian age and has been down faulted for hundreds to thousands of feet along the zone of faulting now occupied by the metavolcanic rocks.

Stratigraphy and structure in Marenisco-Watersmeet area

Recently completed mapping by E. C. Fritts in the Marenisco-Watersmeet area, northern Michigan, has shown that numerous limy lenses, which are characteristic of the so-called "Michigamme Slate" about 50 miles to the east, are at two widely separated stratigraphic levels. They are within a monoclinal and conformable sequence of graywacke, slate, and volcanic rocks at least 40,000 feet thick. This monoclinal sequence includes the Copps Formation of Allen and Barrett (1915)[39] and four overlying formations, two of which consist mainly of metavolcanic rocks. A 15-foot basal conglomeratic quartzite of the Copps Formation still is correlated with the Goodrich Quartzite of the Marquette district, where it is below the Michigamme Slate. At least 10,000 feet of graywacke and slate of the Copps Formation and many thousands of feet of similar graywacke and slate in the upper part of the monocline near Paulding resemble typical Michigamme Slate. Furthermore, in the eastern part of the Marenisco-Watersmeet area, rocks in the monocline trend eastward toward a broad area underlain by graywacke and slate long thought to be physically continuous with rocks in the type area of the Michigamme Slate. Therefore, the monoclinal sequence in the eastern part of the area is interpreted as one of the least deformed parts of the "Michigamme slate series" of Allen and Barrett (1915, p. 131),[39] which unconformably overlies the "middle Huronian" iron-bearing sequence of the Gogebic Range. The "Michigamme slate series" of Allen and Barrett in the monocline is equivalent to rocks that unconformably overlie the Menominee Group within the Animikie Series.

[39] R. C. Allen and L. P. Barrett, 1915, Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geol. Survey Pub. 18 (Geol. Ser. 15), p. 13–164.

Keweenawan stratigraphy in western part of northern Michigan

Keweenawan volcanic rocks in the Ironwood-Bessemer area include two major stratigraphic sequences, according to H. A. Hubbard, rather than one as believed previously. The northern part of the sequence of volcanic and interbedded sedimentary rocks strikes roughly eastward and can be traced by its magnetic properties into the Portage Lake Lava Series of Keweenaw Point. This northern part of the sequence includes many ophitic basalts, very few porphyritic basalts, some sandstone of moderately well sorted subrounded grains, and associated conglomerate.

The southern part of the Keweenawan rocks of the Ironwood-Bessemer area and to the west forms a series of bluffs, the "South Range," that closely parallels the northern part of the sequence; eastward the strike of the sequences diverges markedly, and layers of the South Range swing southeastward toward the south end of Lake Gogebic. The northern part of the sequence in the South Range includes many very fine to fine-grained flows, some of which contain feldspar phenocrysts ¼ to ½ inch long. Tuff or tuff conglomerate is also present. The southern, and oldest, part of the sequence in the South Range is composed of thin fine- to medium-grained flows.

The differences in rock type, topographic expression, areal magnetic patterns (P. W. Philbin and J. L. Vargo, r1728, r2102) and the remnant magnetism described by Books and Beck (described below) indicate that the rocks in the South Range are not a faulted repetition of the Portage Lake Lava Series. The divergent strike eastward suggests an unconformity between the two rock sequences.

Paleomagnetic study in Keweenawan sequence in Lake Superior region

Studies by K. G. Books and M. E. Beck, Jr., indicate that the paleomagnetic field in samples of the lower sequence of Keweenawan lava flows on the northwest and south sides of Lake Superior is significantly different in direction and opposite in polarity from the field in succeeding middle Keweenawan flows, as well as in the upper Keweenawan Copper Harbor Conglomerate. This same reversal of field in the lower sequence of flows is exhibited at other localities[40] around the periphery of Lake Superior, suggesting an equivalent extrusion time for all. In addition, the widespread occurrence of the field reversal indicates a significant paleomagnetic marker horizon that can be utilized for stratigraphic correlation in further paleomagnetic studies in the Lake Superior region.

Block faulting on Isle Royale in Lake Superior

Geologic mapping recently initiated in Isle Royale National Park, Mich., by N. K. Huber has revealed a complex pattern of block faults not shown on the only previous geologic map.[41] These faults result in apparent local thickening of the stratigraphic section, which has led to some confusion in interpretation of the earlier mapping. On the other hand, the gross stratigraphic relationships worked out by Lane and the general correlation with the Keweenawan section on the Keweenaw Peninsula appear to be possible.

WISCONSIN

Precambrian of central and part of northern Wisconsin

A compilation and interpretation of all geologic and magnetic data for the area of Precambrian rocks in Wisconsin are being made by C. E. Dutton and R. E. Linebaugh.

In the southern part of the area, from south of Wisconsin Rapids to north of Wausau there is an apparently complex and random distribution mainly of granite, metagabbro, and greenstone. Rhyolite, syenite, and migmatite are prominent locally but presumably not systematically.

In the northern part of the area, granite, metamorphosed mafic extrusive and probably some intrusive rocks, and metasedimentary rocks that locally include iron-formation underlie belts of prominent northeast trend.

The two areas are separated by one in which glacial deposits are so extensive and thick that the bedrock geology is virtually unknown.

MINNESOTA

Subsurface sand and gravel ridges of glacial Lake Agassiz

Test drilling for ground-water investigations in the Red River valley area of northwestern Minnesota has revealed four north- or south-trending linear ridges of sand and gravel in the subsurface sediments of glacial Lake Agassiz, according to R. W. Maclay and T. C. Winter. The ridges are up to 30 miles long and 1 to 5 miles wide, and, although they have very little surface expression, extend more than 100 feet in depth. Three of the ridges, which grade into lacustrine silt and clay to the east and west along their entire length, were probably formed by melt-water streams flowing from the ice into the proglacial lake during the existence of Lake Agassiz I. The linear ridges suggest that the largest portion of Lake Agassiz sediments were deposited during the existence of Lake Agassiz I and a smaller amount during Lake Agassiz II.

[40] P. M. DuBois, 1962, Paleomagnetism and correlation of Keweenawan rocks: Canada Geol. Survey Bull. 71, 75 p.

[41] A. C. Lane, 1898, Geological report on Isle Royale, Mich.: Michigan Geol. Survey Rept. 6, pt. 1, 281 p.

OHIO

Contact of Delaware and Columbus Limestones in northern Ohio

Identification of the Tioga Bentonite Bed in an outcrop south of Sandusky by W. A. Oliver, Jr., has been confirmed through X-ray analysis by J. W. Hosterman. The Tioga occurs at the contact between the Columbus and Delaware Limestones (just above the "bone bed"). This position of the Tioga, plus biostratigraphic data, indicates that the Columbus is the almost exact equivalent of the lower three members of the Onondaga Limestone of New York. The Delaware is largely equivalent to the Seneca Member, although it is likely that the top of the outcropping Delaware is significantly younger than the top of the Seneca. Examination of core sections in lakeshore areas of Ohio east of the outcrop indicates that the Columbus-Delaware contact descends to the east.

NORTH DAKOTA

Sheyenne delta of glacial Lake Agassiz

A deposit of mainly well sorted sand and silt with minor amounts of gravel extends over a fan-shaped area of about 750 square miles in Ransom, Sargent, and Richland Counties in southeastern North Dakota. The deposit is bounded on the northeast and southeast sides by sediments that accumulated in glacial Lake Agassiz, but glacial till bounds it on the other sides; it has been interpreted by some as a delta and by others as ice-contact stratified drift. Data on gradation of grain sizes from recent test drilling and field observations substantiate deposition as a delta on which the steep northeast edge is probably a wave-cut "cliff" rather than the presumed ice-contact face, according to C. H. Baker, Jr. (p. B62–B68).

KANSAS

Two tills of Kansan age in northeastern Kansas

Stratigraphic studies in northeastern Kansas using pedology, palynology, and clay mineralogy are reported by C. K. Bayne and H. G. O'Connor to indicate that till of Kansan age is divided into two parts by a poorly developed soil and has a strongly developed soil (Yarmouth) in the upper part of the upper till. The illite-kaolinite ratio of the lower till is greater than 1.0 whereas that of the upper till is always less than 1.0.

A strongly developed, locally truncated soil at the top of fluvial deposits below the lower till is considered to be an interglacial (Aftonian) soil. A soil below the fluvial deposits was developed on shallow-lake or marsh deposits which overlie gravel containing glaciated pebbles (possibly they are pebbles derived from till).

Pollen analyses show corresponding changes within these deposits. The pollen analyses together with the presence of two soils in these pre-Kansan deposits may be an indication of two advances and retreats of the glacier during the Nebraskan Glaciation.

Clay-mineral assemblages were of no aid in differentiating the nontill deposits.

INTERIOR HIGHLANDS AND EASTERN PLAINS

ARKANSAS

Age of Stanley Shale and Jackfork Sandstone in central Arkansas

New information on the age of the Stanley Shale and the overlying Jackfork Sandstone is being acquired through the study of fossils by Mackenzie Gordon, Jr. The fossils were collected by Charles Stone and other members of the Arkansas Geological Commission at localities within a few miles of Little Rock during their mapping program. Preliminary results of the study indicate that the upper part of the Stanley Shale and likewise the entire Jackfork Sandstone in this region is Pennsylvanian in age. The fossils include ammonoids typical of the Hale Formation of early Morrow (Early Pennsylvanian) age in northwest Arkansas.

OKLAHOMA

Fossils from Cotter Dolomite near Spavinaw

Determinations were made by E. L. Yochelson of fossils from an outcrop of Cotter Dolomite one-half mile southwest of Spavinaw in northeast Oklahoma, in a composite collection made through the years by various geologists including H. S. Williams, C. E. Siebenthal, E. O. Ulrich, Josiah Bridge, H. D. Miser, Sidney Powers, L. G. Henbest, and George Buchanan. These determinations constitute the first list of Cotter fossils from northeast Oklahoma and are of particular significance at this time because of renewed interest in the relations between the granite at Spavinaw and the overlying rocks. The fossils consist of algal, sponge, gastropod, orthoconic cephalopod, and possible trilobite remains. Yochelson believes that the Lower Ordovician gastropods, which include *Orospira bigranosa* Butts, *Eotomaria?* sp., *Lesueurilla* sp. indet., and *Hormatoma* cf. *H. lutiensis* Cullison, as well as the operculum *Ceratopia tennesseensis* Oder from a nearby outcrop, belong to that part of the Cotter that Cullison (1944)[42] called the Theodosia Formation.

NORTHERN ROCKY MOUNTAINS AND PLAINS

WASHINGTON

Early Eocene volcanism and plutonism in northeast Washington

Synchronous volcanism and plutonism in early Eocene time are indicated by geological investigations in northern Ferry and Okanogan Counties by R. C. Pearson. Isotopic ages (K–Ar) determined by J. D. Obradovich on samples from the Sanpoil Volcanics, Scatter Creek Formation, and associated plutons of quartz monzonite and granodiorite range from 51 to 54 m.y. The volcanic rocks are preserved in grabens, in fault contact with the contemporaneous plutonic rocks. Still older plutons in the region may be Cretaceous.

Possible major structural discontinuity

A matching of stratigraphic and petrologic elements of the Kootenay arc—a southwest-trending fold belt that dominates the structure of northeastern Washington—with similar elements to the southwest is believed by R. G. Yates to be evidence for an ancient strike-slip fault with a left-lateral displacement of as much as 400 miles. The line along which offsets apparently occur trends S. 50° E. from southeastern Washington through central Idaho possibly as far as western Wyoming. The exact relationships are largely obscured by lavas of the Columbia Plateau and granitic rocks of the Idaho batholith.

Belt Series differentiated

A. B. Griggs reports that the Prichard, Burke, Revett, St. Regis, Wallace, Striped Peak, and Libby Formations of the Belt Series are all persistent and readily mappable over much of the Spokane quad-

[42] J. S. Cullison, 1944, The stratigraphy of some Lower Ordovician formations of the Ozark uplift: Missouri Univ. School Mines and Metallurgy Tech. Ser. Bull., v. 15, no. 2, 112 p.

rangle (1° by 2°) in east-central Washington and west-central Idaho. Individual units display considerable lateral variations in thickness and lithology.

Differentiated intrusives from northeastern Washington

F. K. Miller has prepared modal quartz–K feldspar–plagioclase diagrams for eight different plutons in the Chewelah No. 1 and 4 quadrangles, Stevens County. The average modal composition for seven of the plutons falls on a straight line extending from quartz-poor granodiorite to quartz-rich quartz monzonite. This suggested differentiation trend is supported by color index and by sequence of intrusion where it can be established.

IDAHO

Purcell trench not a single continuous structure

Subsidiary branching of the Hope fault suggests that the Purcell trench, stretching from Coeur d'Alene Lake in Idaho northward to Kootenay Lake in Canada, is not a continuous structural entity. Several faults mapped by J. E. Harrison north of Lake Pend Oreille appear to cut diagonally west and northwest across the trench, thereby segmenting it into several individual structures.

Caldera at Thunder Mountain

Reconnaissance geologic studies in the Idaho primitive area by F. W. Cater, W. B. Hamilton, B. F. Leonard, R. L. Parker, and E. V. Post have resulted in the recognition of a caldera at Thunder Mountain, 18 miles east of Yellow Pine. The caldera is a triangular topographic depression at the center of a crudely circular volcanic field that extends for 35 miles from Big Creek settlement southeast to the Middle Fork of the Salmon River. The widespread Challis Volcanics of Tertiary age in central Idaho may have been derived from this vent, rather than from a system of buried fissures that had been inferred from earlier investigations.

New data on thrust faults in southeast Idaho

A segment of the Putnam thrust [43] has been reexamined by D. E. Trimble in the Yandell Springs quadrangle, south-central Bingham County, and found to be a zone of north-trending imbricate thrust faults offset by east-trending tear faults. One tear fault with left lateral movement offsets the easternmost thrust fault about 3½ miles.

Interpretation of subsurface geologic structures on the northward extension of the Bear River valley north and northeast of Soda Springs, Caribou County, indicates that the buried Paris thrust fault [44] passes between Chester Hill on the west and Threemile Knoll on the east. F. C. Armstrong reports that the stratigraphic throw at this locality is only 60 percent of the throw at the nearest exposure of the fault, 14 miles to the southeast, and suggests that movement along the thrust dies out progressively northward.

Early Mississippian age for basal Milligen Formation confirmed

An Early Mississippian (early Kinderhook) conodont fauna was found by C. A. Sandberg and others (p. C127–C131) in black crinoidal limestone in the basal part of the Milligen Formation near Mackay, on the west side of the Lost River Range, east-central Idaho. The conodonts are the first diagnostic fossils recovered from the Milligen.

Cache Valley graben and Lake Bonneville

Tectonic events as well as climatic changes contributed to the development of Pleistocene Lake Bonneville, according to studies by S. S. Oriel and L. B. Platt in the northern part of Cache Valley, southeast Idaho. The valley, which was flooded by Lake Bonneville, is bounded by steep normal faults that have more than a mile of throw and that place strata of the Salt Lake Formation (Pliocene) in the central, downdropped block against Precambrian rocks on either side. Recent earthquakes recorded in the region have been along the fault on the east side of the Cache Valley graben.

Varved lake beds in northern Idaho

E. H. Walker reports (p. B83–B87) that thick deposits of fine-grained sediment underlie the floors of the Purcell trench, the Pend Oreille Valley and adjacent lowlands, and the Priest River valley in northern Idaho. These deposits, consisting of interbedded sand, silt, and varved clay, formed in a lake that was dammed by ice across the Pend Oreille River in late Pleistocene time.

MONTANA

Volcanic-rich conglomerates clue to buried plutons

Recent studies in the Sun River area, central Montana, by M. R. Mudge has disclosed volcanic-rich conglomerates in the Kootenai Formation, Vaughan Member of the Blackleaf Formation, and Horsethief Sandstone. These conglomerates (Early to Late Cretaceous in age) are all identical in composition, and were likely derived from an Upper Jurassic

[43] G. R. Mansfield, 1920, Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U.S. Geol. Survey Bull. 713, 152 p.

[44] F. C. Armstrong, and E. R. Cressman, 1963, The Bannock thrust zone, southeastern Idaho: U.S. Geol. Survey Prof. Paper 374-J, p. J1–J22.

intrusive body. The cobble size (maximum 7 inches) indicates a source closer to the Sun River area than the nearest known outcrops of Jurassic igneous rocks in southern British Columbia, 200 miles away. The source possibly was a nearby pluton that was subsequently buried by younger thrust faults.

Ultramafic diatremes discovered near Helena

G. D. Robinson reports that several small ultramafic diatremes intrude the Flood Member of the Blackleaf Formation (Lower Cretaceous) in the Beartooth Mountain quadrangle, about 25 miles northwest of Helena. The host rock near the diatremes is highly deformed, and is part of a thrust plate. The intrusions consist mainly of chaotically mixed fragments of black shale and slightly serpentinized ultramafic rock. They occur in pluglike masses several feet across and in thin dikes a few tens of feet long.

Domal uplift overridden by advancing thrust sheet in central Montana

In and east of the Nelson quadrangle, northwest of Lake Helena in central Montana, the several branches of the Moors Mountain thrust were folded progressively during transport, according to recent studies by W. B. Myers. The oldest branch is folded recumbently, but successively younger branches are less deformed. The field relations indicate that a domal uplift arose across the path of the easterly advancing bedding-plane glide sheet, and that the dome was then overridden by younger segments of the thrust.

Landslides diverted Whitetail Creek

H. J. Prostka reports (p. B80–B82) that three or more landslides of probable Pleistocene origin dammed the valley of Whitetail Creek, which flows into the Jefferson River about 12 miles east of Butte. The landslides diverted the stream and caused it to become incised partly in bedrock and partly in landslide debris. The resulting valley profiles are distinctive and unusual for the region.

Sequence of tectonic events determined in Wolf Creek area

Detailed mapping by R. G. Schmidt in the Roberts Mountain quadrangle, near Wolf Creek in Lewis and Clark County, has revealed the following sequence of tectonic events: (1) intense deformation of the Mesozoic rocks; (2) emplacement of the Eldorado overthrust (southern extension of the Lewis thrust zone), containing a thick plate of upper Precambrian rocks of the Belt Series; and (3) deformation of both the thrust sheet and the underlying Mesozoic rocks by folding and normal faulting.

Disharmonic folds along west edge of Crazy Mountains Basin

Large anticlines whose amplitude decreases downward characterized late Paleocene deformation along the west edge of the Crazy Mountains Basin in Gallatin and Park Counties, according to B. A. Skipp. The folds trend north and northwest and their axial surfaces are inclined toward the west. Beds ranging in age from Precambrian to Paleocene are involved in the folding; one fold was observed to die out at depth in the upper Precambrian Spokane Shale.

YELLOWSTONE NATIONAL PARK

Two major ash-flow sheets differentiated in central Yellowstone

R. L. Christiansen and H. R. Blank report that the Yellowstone Tuff of Boyd (1961),[45] a large-volume ash-flow deposit of the Yellowstone Rhyolite Plateau, consists of two major ash-flow sheets separated by an erosional unconformity. Differences were observed in areal distribution, internal lithologies, and magnetic properties. Possible source areas are: (1) the Island Park Caldera,[46] just west of the park, for the lower ash-flow sheet, and (2) a caldera, now buried by younger rhyolite flows in central Yellowstone, for the upper ash-flow sheet.

Yellowstone Lake basin former site of thick ice accumulation

Studies of Quaternary deposits in southeastern Yellowstone National Park by G. M. Richmond and K. L. Pierce indicate that a late Pleistocene (Pinedale Glaciation) center of ice accumulation developed in the Yellowstone Lake basin. At its maximum, the ice flowed east across the Absaroka Mountain crest, as well as radially in other directions. Deposits of an older glaciation (Bull Lake Glaciation) underlie the Pinedale deposits locally.

Complex facies in volcanic rocks of Absaroka Mountains

Geologic mapping and stratigraphic studies by H. W. Smedes and H. J. Prostka reveal complex facies changes in volcanic rocks of the Absaroka Mountains along the east side of Yellowstone National Park. The variations in composition, texture, and bedding characteristics reflect not only distance from the contributing vent, but also indicate that several different vents were involved in the eruptions. The base of the vol-

[45] F. R. Boyd, 1961, Welded tuffs and flows in the rhyolite plateau of Yellowstone Park, Wyoming: Geol. Soc. America Bull., v. 72, p. 387–426.

[46] W. B. Hamilton, 1965, Geology and petrogenesis of the Island Park Caldera of rhyolite and basalt, eastern Idaho: U.S. Geol. Survey Prof. Paper 504–C, p. C1–C37.

canic pile transgresses southward; the lowermost rocks of the sequence are approximately 4,000 feet higher stratigraphically in the southeastern part of the park than in the northeastern part.

Thrust faults complicate classic Devonian section

The Devonian rocks on Crowfoot Ridge in northwestern Yellowstone National Park, long considered to be typical of the region, are broken by thrust faults, according to E. T. Ruppel. An unfaulted section of Devonian rocks, on the other hand, is exposed at Three Rivers Peak, a few miles southeast of Crowfoot Ridge.

Structures delineated in south-central Yellowstone

Structural elements in the Paleozoic and Mesozoic sedimentary rocks of south-central Yellowstone National Park have been outlined by W. R. Keefer and M. F. Gregorich as follows: (1) highlands bounded by nearly vertical faults on the west; (2) a central, structurally low area occupied by large folds; and (3) a thrust block on the east. These are continuations of structures observed in Jackson Hole and adjacent regions to the south; they also extend northward an unknown distance beneath middle and upper Tertiary volcanics of the central Yellowstone region.

Structural control of circulation of hydrothermal fluids

Detailed gravity surveys of parts of Upper and Lower Geyser Basins reveal belts of gravity lows (amplitude 2 mgal) that trend north-northwest, parallel to a prominent regional joint pattern. The anomalies are interpreted by H. R. Blank as reflecting decreases in density of rhyolite bedrock by hydrothermal solution, and their distribution appears to support a hypothesis that master joints of the north-northwest set acted as structural controls for the deep circulation of hydrothermal fluids.

WYOMING

Structure of Wind River Basin outlined

Structure contours of the top of the Permian rocks show that the reverse-fault zone at the boundary between the Wind River Basin to the south and west and the Owl Creek Mountains and Casper arch to the north and east is essentially continuous for about 110 miles. According to W. R. Keefer, stratigraphic displacements locally exceed 20,000 feet and maximum structural relief is about 32,000 feet. The top of the Precambrian basement along the major basin trough line is locally nearly 25,000 feet below sea level.

Ancient structure clue to petroleum accumulation in central Wyoming

Triassic strata above the Alcova Limestone thin markedly across oil- and gas-producing anticlines along the east edge of the Wind River Basin and west edge of the Powder River Basin, according to J. D. Love and J. A. Van Lieu. Pre-Late Jurassic structural movements as manifested by the thinning may have significantly influenced accumulation of the petroleum.

Age ranges of Mississippian rocks determined

Numerous fossil collections from the Madison Limestone by W. J. Sando indicate that the formation ranges in age from Kinderhook into early Meramec over much of central and northern Wyoming and southern Montana. The top of the Madison is an erosional surface with a possible age range of middle Meramec to early Chester. The overlying Darwin Sandstone Member of the Amsden Formation is probably no younger than Chester throughout the area.

Jurassic and Triassic rocks subdivided in south-central Wyoming

Regional stratigraphic studies of the Jurassic rocks in south-central Wyoming by G. N. Pipiringos have led to the recognition of seven members in the Sundance Formation. These are, from top to bottom: Windy Hill Sandstone (new name), Redwater Shale, Pine Butte (new name), Lak, Hulett, Stockade Beaver Shale, and Canyon Springs Sandstone Members. In addition, the Triassic Chugwater Formation has been reclassified as a group by Pipiringos, and the Popo Agie, Crow Mountain Sandstone, Alcova Limestone, and Red Peak, formerly members, have been raised to formational status. In southeastern Wyoming the Jelm Formation (Crow Mountain Sandstone equivalent) is incorporated in the Chugwater Group. The Nugget Sandstone is divided into an upper, unnamed member of Triassic(?) and Jurassic(?) age and the lower, Bell Springs Member (new name) of Triassic(?) age.

Extension of Darby thrust

H. F. Albee, M. L. Schroeder, and D. A. Jobin have mapped the Darby thrust fault in extreme western Wyoming from Munger Mountain northwest for about 27 miles to a point where it dies out in the Lower Cretaceous Bear River Formation (p. D1–D3). Previous investigators ended the fault on the east side of Munger Mountain near the confluence of the Hoback and Snake Rivers.

Rate of movement of Teton Glacier determined

A resurvey in 1966 of markers that had been placed across the Teton Glacier near the snowline in 1963, 1964, and 1965 indicates that the average rate of ice movement near the center of the glacier is about 28 feet per year, according to J. C. Reed, Jr. (p. C154–C159) Locally, the terminus has advanced as much as 30 feet, but most of it remains in about the same position as in 1963. Measurements near the surveyed profile show that the ice is about 64 feet thick, and that the central part of the glacier was 2 to 8 feet thicker in 1966 than in 1963.

New evidence for major Laramide basin in northwest Wyoming

Additional evidence has been obtained for the existence of a major Laramide sedimentary and structural basin in northwestern Wyoming. The basin, extending along the entire northeast margin of the Gros Ventre Mountains and north as far as south-central Yellowstone National Park, was the site for accumulation of several thousand feet of fluviatile sediments in Late Cretaceous and early Tertiary times. J. D. Love and J. L. Weitz, during the 1966 field season, collected fossils identified by D. W. Taylor as brackish-water oysters or inoceramid clams from strata about 5,000 feet stratigraphically above the base of the Paleocene Pinyon Conglomerate. The fossils indicate marine or near-marine conditions, and the region must have stood about at sea level in late Paleocene time. Uppermost Cretaceous rocks now at altitudes above 6,000 feet were as much as 10,000 feet below sea level during Laramide basin subsidence.

SOUTH DAKOTA

New fault mapped in Black Hills

A previously unreported fault that extends from the eastern flank of the Black Hills and into the central core, near Rapid City, has been mapped. The fault, termed the Victoria Creek fault by J. M. Cattermole, trends N. 55°–65° W., and cuts both Paleozoic and Precambrian rocks at a high angle. Maximum stratigraphic throw is more than 300 feet, where Precambrian rocks are upthrown against Mississippian strata. The fault has been traced in Precambrian rocks west to the community of Hisega, and a topographic lineation beyond Hisega suggests that the fault may continue still farther northwestward.

SOUTHERN ROCKY MOUNTAINS AND PLAINS

COLORADO

Tarryall Mountains batholith

The Tarryall Mountains batholith in Park and Jefferson Counties has been found by C. C. Hawley to be Pikes Peak Granite (Precambrian), but the batholith is distinct from the main Pikes Peaks batholith to the east. It is pear-shaped in plan, about 100 square miles in area, and composed of 3 main zones: a discontinuous outer zone of medium-coarse granite, a continuous middle zone of coarse subequigranular granite, and an inner zone of coarse porphyritic alkali granite. Averages of 7 analyses of the inner-zone granite give 4 ppm Be, 77 ppm Li, 83 ppm Nb, 447 ppm Rb, and 15 ppm Sn. The trace-element content of the inner-zone granite is very similar to that of the slightly younger, but still Precambrian, Redskin Granite (C. C. Hawley and others, r0099) to the south.

Precambrian history near Salida

A few miles northeast of Salida, Chaffee County, C. T. Wrucke has found that a thick sequence of biotite gneiss and hornblende gneiss was invaded by a granitic mass of batholithic dimensions, then deformed twice before Cambrian time. The first clearly recognized deformation produced isoclinal folds and mineral alinements in the gneisses, and crushed and recrystallized the border of the granitic batholith during metamorphism of sillimanite grade. Hook-shaped bodies and fold axes of diverse trends suggest an even earlier, but not positively established, deformation. The youngest Precambrian deformation produced open folds and was not accompanied by high-grade metamorphism.

Precambrian rocks in Rocky Mountain Arsenal well

D. M. Sheridan and others[47] found in a petrographic study of drill cuttings and cores from the lower part of the 12,045-foot-deep disposal well at the Rocky Mountain Arsenal, about 10 miles northeast of Denver, that the Precambrian rocks consist of migmatitic gneiss upon which a regolith probably had developed before deposition of the overlying Paleozoic rocks. Open fractures, as well as veinlets and microbreccias, cross the gneiss of the drill cores. The veinlets and microbreccias resemble features in and near breccia-reef faults that transect Precambrian rocks in the Front Range to the west. The similarity between many features of the microbreccias in the drill cores and the breccia reefs and the presence of fractures in cores recovered from the overlying Fountain and Lyons Formations (Pennsylvanian and Permian)[48] suggest that a fault or fracture zone may occur in the vicinity of the deep disposal well.

[47] D. M. Sheridan, C. T. Wrucke, and R. E. Wilcox, 1966, Petrography of the Precambrian rocks from the deep disposal well, Rocky Mountain Arsenal, Adams County, Colorado, *in* J. H. Healy and others, Geophysical and geological investigations relating to earthquakes in the Denver area, Colorado: U.S. Geol. Survey open-file report, pt. 4, 17 p.

[48] L. J. Scopel, 1964, Pressure injection disposal well, Rocky Mountain Arsenal, Denver, Colo.: The Mountain Geologist, v. 1, no. 1, p. 39, 40.

Precambrian sheer zone in northwestern Colorado

In Routt and Jackson Counties, G. L. Snyder has recognized a major Precambrian shear zone as much as 3½ miles wide that trends northeasterly across the Park Range in the vicinity of Buffalo Pass. The zone is identified by numerous mylonite layers, ½ inch to 50 feet thick. Left lateral displacement is indicated by drag of metasedimentary units and by offset of vertical postmetamorphic Precambrian porphyry dikes. The cumulative dike offset is about ½ mile, but displacement prior to the intrusion of the dikes is thought to have been much greater.

Intrusive aureoles in Precambrian gneiss, north-central Colorado

D. J. Gable reports that in the Nederland area of north-central Colorado, Tertiary intrusive bodies have produced distinctive changes in Precambrian biotite gneiss and hornblende gneiss. Outward from the contact for about 1,000 feet the gneisses are recrystallized and the original foliation has been altered or destroyed. A hornfelsic texture is formed only adjacent to the intrusives. An aureole of mineralogic changes extends 2,000 to 2,500 feet from the intrusive bodies. Orthoclase totally or partially replaces microcline, and cordierite and magnetite replace garnet in biotite gneiss. In hornblende gneiss, some biotite and potassium feldspar have been formed. The aureoles of textural and mineralogical changes may prove useful in determining the presence and size of unexposed Tertiary intrusives.

A relation between Minturn Formation and Gothic Formation of Langenheim

Fossils have been collected by Bruce Bryant from a limestone bed of local extent near the top of the Gothic Formation of Langenheim (1952)[49] from the southwest corner of the Maroon Bells quadrangle in Gunnison County. As determined by Mackenzie Gordon, Jr., and E. L. Yochelson, the fauna of that bed more nearly resembles that of the White Quail Limestone Member of probable Des Moines age than that of the Jacque Mountain Limestone Member. On the other (northeast) side of the central Colorado trough, the Jacque Mountain Limestone Member marks the top of the Minturn Formation and is 950 feet above the White Quail Limestone Member.

Upper part of Minturn Formation possibly of Permian age

Fossils from beds mapped by G. R. Scott as the upper part of the Minturn Formation near Coaldale in Fremont County include *Calamites*(?) *huerfanoensis* Arnold and several species of pollen and spores identified by R. A. Scott and L. I. Doher. The presence of bisaccate gymnospermous pollen, in particular striate bisaccates, plus the calamite, suggests that the upper part of the Minturn Formation near Coaldale may be Permian rather than Pennsylvanian in age.

Domes near Lamar

J. A. Sharps reports that structural contours of the top of the Cretaceous Dakota Sandstone suggest the presence of two domes northeast of Lamar in southeast Colorado. One, about 4 by 6 miles in size, is centered in T. 21 S., R. 46 W.; the other, about 4 by 7 miles in size, is centered in T. 21 S., R. 44 W. Each has a closure in excess of 50 feet. These highs may have been formed by subsidence in the areas to the southwest and southeast resulting from solution of underlying beds.

Contemporaneous faulting and intrusion near Aspen

Geologic mapping in the Richmond Hill area near Aspen, Pitkin County, by Bruce Bryant indicates that the Tertiary igneous rocks there were emplaced concurrently with high-angle faulting, although some faulting continued after their emplacement. This interpretation differs from that of Spurr[50] and Knopf,[51] who believed that the igneous rocks were emplaced before deformation. Age differences between the several types of intrusive igneous rocks in the area, based on whether faults or bedding controlled their emplacement, appear to be insignificant.

Oligocene volcanism and mineralization in central Front Range

K-Ar age determinations made by H. H. Thomas, R. F. Marvin, and Paul Elmore and reported by P. K. Theobald and R. B. Taylor on sanidine phenocrysts separated from rhyolite from Red Mountain (near the foot of Berthoud Pass) and from tuffs from the Fraser basin and the Kremmling basin show that an episode of rhyolitic volcanism took place about 30 m.y. ago in the central Front Range. The gross features of the basin and mountain topography had been defined by tectonism and erosion by that time. The molybdenum ores and associated mineralization at Red Mountain were formed during this volcanic episode.

Volcanism in San Juan Mountains

Continuing work by T. A. Steven and P. W. Lipman in the San Juan Mountains of southwest Colorado has shown that the central San Juan cauldron complex

[49] R. L., Langenheim, Jr., 1952, Pennsylvanian and Permian stratigraphy in Crested Butte quadrangle, Gunnison County, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 4, p. 543–547.

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

[51] Adolph Knopf, 1926, Recent developments in the Aspen district, Colorado: U.S. Geol. Survey Bull. 785, p. 1–28.

was the source of at least 12 major ashflow sheets of several thousand cubic miles original volume. The complex is at least 50 miles long and 15 to 25 miles wide. Six cauldrons definitely have been identified, two more probably are present, and several more may be present. They form an overlapping mosaic in which younger cauldrons show their original form, whereas the older cauldrons have been variably obliterated or covered. The related eruptions and subsidences took place within 2 million years in latest Oligocene time.

Volcanism in central Colorado dated

A volcanic sequence more than 500 feet thick that consists of pumiceous tuff and breccia, perlite, and lithophysal rhyolite with small crystals of gem-quality spessartite garnet and topaz is reported near Nathrop, Chaffee County, by R. E. Van Alstine. Three K-Ar age determinations (analysts, R. F. Marvin, H. H. Mehnert, W. M. Mountjoy, and V. M. Merrit) indicate that the flows were erupted in late Oligocene time, 28 to 29.3 m.y. ago ($\pm$ 0.8 to 1.5 m.y.). The determinations were made on obsidian pellets from the perlite and on sanidine crystals concentrated from samples of a phenocryst-rich part of the rhyolite flow.

Cauldronlike volcanic center in central Colorado

In their work on the Thirtynine Mile volcanic field of central Colorado, R. C. Epis and J. E. DuHamel have mapped part of a previously unknown cauldronlike volcanic center near Thirtyone Mile Mountain. The oldest ash-flow tuffs of the field, local flows, bedded breccias, and domes appear to have erupted from this center. The cauldronlike center is overlapped by an elliptical caldera near Guffey. Numerous subvolcanic intrusive bodies in the caldera, together with caldera ring-zone faults, locally control hydrothermal alteration and slight mineralization.

Uncompahgre River history

R. G. Dickinson, working in the Colona quadrangle in western Colorado, found Quaternary stream-channel deposits that mark a former course of the Uncompahgre River. The deposits occur in north-trending isolated patches along the east side of the quadrangle and are 620 to 690 feet above the present river. They are overlain by composite landslide debris which originated from the east. A strong pre-Wisconsin soil locally is developed within the landslide debris. Two separate occurrences of air-fall rhyolitic volcanic ash were found among the landslide debris. Preliminary study of the ash by R. E. Wilcox indicates that it is mineralogically similar to the Pearlette Ash Member of the Sappa Formation of Kansan or Yarmouth age in Nebraska. If correlation of this ash with the Pearlette is valid, downcutting by the Uncompahgre has been as much as 690 feet since Kansan time.

Soils on upper Quaternary deposits near Denver

Soil-stratigraphic relations studied by Richard Van Horn (p. D228–D232) along Indian Creek south of Denver suggest that a previously unrecognized possible soil-forming interval occurred soon after deposition of the Broadway Alluvium, and before renewed downcutting and deposition of the next younger pre-Piney Creek alluvium. Thus, there may have been 4 intervals of soil-profile development in Wisconsin and Recent time instead of the 3 intervals previously recognized.

Geophysical data in north-central Colorado

J. C. Behrendt reports that Bouguer anomalies range from —210 mgal over Precambrian rocks in the Mountains to —258 mgal in the Walden syncline and —282 mgal in the North Park syncline. The anomalies over these synclines are partly the result of the low-density Upper Cretaceous and younger sedimentary rocks. Steep gradients delineate a normal fault which strikes about west-northwest along the north flank of the North Park syncline; vertical displacement is about 3 km. Seismic refraction work in this syncline shows velocities increasing from 2.5 to 3.4 km per sec in the Tertiary Coalmont Formation. The older sedimentary rocks have a velocity of 4 to 4.5 km per sec. Precambrian basement is present along the profile at a depth of 4 km and has a velocity of 6.25 km per sec.

NEW MEXICO

Subdivision of upper part of Madera Limestone

During mapping of the Torreon, Tajique, and Escabosa quadrangles in central New Mexico, D. A. Myers[52] (r2010) recognized two periods of erosion in the upper part of the Madera Limestone that are marked by channel-filling arkosic sandstone and conglomerate derived from a Precambrian source. These deposits, which range in thickness from less than 5 feet to more than 80 feet, are used to subdivide the upper part of the Madera Limestone in 3 mappable. units. The lower unit rests with apparent conformity on rocks of Des Moines age and is of Missouri age. The middle unit is of early Virgil age and the upper unit is of late Virgil and early Wolfcamp age.

Southern termination of Sangre de Cristo Mountains

The Sangre de Cristo Mountains of north-central New Mexico and south-central Colorado are generally

[52] D. A. Myers, 1966, Geology of the Tajique quadrangle, Torrance and Bernalillo Counties, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–551.

characterized by thrust and tear faults on their east side and normal faults of great displacement on their west side. R. B. Johnson has found that these mountains terminate to the south in a narrow and sinuous monoclinal flexure that pitches to the southeast. Near Bernal, San Miguel County, the maximum vertical displacement across the monocline is 900 feet in a mile. This monocline probably formed by bending of the sedimentary rocks above a fault or faults in the crystalline basement rocks.

Anomalous mass deficiency associated with Valles caldera

Lindreth Cordell has found that large gravity and magnetic minimums are associated with the Valles caldera, Jemez Mountains, north-central New Mexico. The gravity data indicate an anomalous mass deficiency of about 200×10^{15} g, not including an additional mass deficiency of about 20×10^{15} g attributed to surficial lacustrine and pumiceous caldera-fill. The observed negative magnetic anomaly is too large to be satisfactorily explained by surficial causes, such as volcanic flows and caldera-fill. The structural and geophysical data together indicate an intrusive body underlying the caldera, possibly at a depth of about 1 mile and with a thickness of 1 to 3 miles, that (1) has a low density, (2) cooled at least below the Curie temperature, and (3) is reversely magnetized, roughly antipolar with respect to the earth's present magnetic field.

COLORADO PLATEAU

COLORADO

Precambrian stratigraphy

The Precambrian intrusive sequence in the Black Canyon of the Gunnison, southwest Colorado, discloses a progressive denudation of the crust during the protracted period of igneous intrusion, according to W. R. Hansen. The oldest major plutonic unit is a strongly foliated syntectonic granodiorite, not yet formally named, of probable batholithic size, and intruded at katazonal depth. Its contacts are mostly concordant with the enclosing country rock and in part are gradational. The next younger major rock unit, the Vernal Mesa Quartz Monzonite, is phacolithic in form in the Black Canyon area, is partly foliated, and is semiconcordant. It has both katazonal and mesozonal attributes, hence it probably was emplaced near the top of the katazone in a late syntectonic setting. The youngest major rock unit, the Curecanti Quartz Monzonite, is largely posttectonic and was emplaced in a mesoepizonal setting. Many small bodies of this rock are somewhat foliated, but the major body is massive and sharply discordant. Pegmatite, in large and small bodies, probably was emplaced at many different times and depths during the Precambrian era. Diabase, the youngest intrusive rock, is clearly hypabyssal.

UTAH

Jurassic tectonism and sedimentation in southeastern Utah

Irregularities in thickness and lithology of the formations of Jurassic age underlying the Dakota Sandstone of Early(?) and Late Cretaceous age and overlying the Carmel Formation of Middle and Late Jurassic age in the western part of the Escalante quadrangle (1° by 2°) southeastern Utah, are attributable to 3 principal causes, according to D. G. Wyant. The causes are (1) pre-Dakota, post-Morrison tilting and erosion; (2) pre-Summerville, post-Entrada folding and erosion; and, (3) rapid lateral facies changes, perhaps in part brought on by contemporaneous folding.

Cretaceous tectonism and sedimentation in southern Utah

Between the Echo monocline and the southern end of the Kaiparowits Plateau in southern Utah, Fred Peterson finds that the Dakota Sandstone of Early(?) and Late Cretaceous age not only truncates underlying formations of Late Jurassic age (Morrison Formation and Cow Springs Sandstone) but varies in thickness systematically with structure. The Dakota thickens over synclines and grabens and thins over anticlines and horsts. The overlying formations of Late Cretaceous age also seem to vary systematically in thickness. The Tropic Shale thins over at least one anticline, whereas coal of the overlying Straight Cliffs Formation thickens generally in synclines. These findings imply continued or recurrent tectonism in Early(?) and Late Cretaceous time that probably was effective along an earlier established structural "grain" of northwest trend.

Volcanic stratigraphy in southern Utah

Preliminary study of chemical analyses of the volcanic rocks of Cenozoic age in the western part of the Salina quadrangle (1° by 2°) in southern Utah has been made by P. L. Williams and R. J. Hackman. The study indicates a close chemical similarity between latite flows of the Dry Hollow Formation and the latite welded tuff near Osiris. This similarity implies a common source that is probably near the map area, as it is unlikely that the latite flows traveled far from their source vent. The source of both the flows and the tuff near Osiris may be in or near the western part of the Salina quadrangle—possibly near Fish Lake, or in the Marysvale igneous center. Furthermore, both of these latite units are chemically and lithologically similar to welded tuffs of the Isom Formation which is widespread in southwest Utah and occupies an equivalent stratigraphic position. The postulated source area of the latite flows and the welded tuff near Osiris may be the source area of the Isom Formation as well.

ARIZONA

Age of lava dam in Grand Canyon

The isotopically determined age of basalt from the basal flow of the lowermost lavas at the mouth of Toroweap Canyon, in the western part of the Grand Canyon, is 1.16 ± 0.18 m.y. The whole-rock K-Ar determination was made by P. E. Damon (University of Arizona) from samples collected by W. K. Hamblin, (Brigham Young University) in cooperation with E. D. McKee.[53] This represents a minimum age of Grand Canyon, for at the time of lava eruption the canyon was nearly as deep as it is today. Since eruption the Colorado River has cut through the 550-foot lava dam, and only 50 feet into the Paleozoic strata below. In addition, the river has cut through one or more later dams in the area, and through 100 feet of younger intracanyon lavas downstream.

Jurassic stratigraphy in Arizona and Utah

As a byproduct of his plateau-wide stratigraphic study of the San Rafael Group of Middle and Late Jurassic age, J. C. Wright has found thin bentonite beds in the group. Purple bentonite near the base of the group is restricted geographically to a small area in north-central Arizona and southwest Utah. The maximum thickness aggregates 30 feet near St. George, Utah. The source was probably no more than a few tens of miles to the southwest.

In contrast, bentonite beds near the middle of the group are widely distributed in northern Arizona and southeastern Utah. The thickness of these beds aggregates less than 3 feet so far as is now known, with no systematic change in any direction. The source of this bentonite was probably several hundred miles distant. In addition to being diagnostic environmental and stratigraphic "markers," the bentonite beds record a a period of minor volcanism between periods of much greater volcanic eruptions that are indicated by the thick accumulations of bentonitic strata in the Chinle Formation (Upper Triassic) and the overlying Morrison Formation (Upper Jurassic).

[53] E. D. McKee, W. K. Hamblin, and P. E. Damon, in press, K-Ar age of lava dam in Grand Canyon: Geol. Soc. America Bull.

BASIN AND RANGE REGION

NEVADA

Mississippian-Pennsylvanian hiatus in Indian Springs region

Mackenzie Gordon, Jr., reports that additional material from the base of the Pennsylvanian section near Indian Springs, Clark County, indicates a slightly greater hiatus between the Mississippian and Pennsylvanian rocks in this vicinity than heretofore suspected. A specimen originally identified as *Branneroceras* is reidentified as a primitive *Diaboloceras*, which indicates a middle Bloyd rather than early Bloyd age (in terms of the Arkansas type section of the Morrow Series) for the earliest Pennsylvanian rocks in the region.

Tertiary orogeny in Ruby Mountains

Geologic mapping and radiometric dates by R. W. Kistler and C. R. Willden suggest that an episode of orogenic intensity affected the Ruby Mountains of northeastern Nevada during Tertiary time. A series of Rb-Sr whole rock and K-Ar mineral ages ranging from 29 to 40 m.y. has been obtained on pegmatites, granites, and metamorphic rocks within the mountain range and on volcanic rocks in the adjacent valley to the west. The 40-million-year-old beryl-bearing pegmatites cut folds that have deformed a large pluton dated at 65 m.y. by Rb-Sr methods. These data suggest that the last episode of folding occurred between 65 and 40 m.y. ago and that it was closely associated in time with intrusion of granitic rocks and volcanic activity.

Mercury mineralization in southern Ruby Valley

Mapping in the southern Ruby Mountains and the Cherry Creek Range, White Pine County, by R. K. Hose and M. C. Blake, Jr., has disclosed extensive outcrops of jasperoid breccia which contains anomalous amounts of mercury. A magnetic anomaly of about 500 gammas has been mapped in the southern end of Ruby Valley. Samples of the jasperoid breccia and bedrock peripheral to the magnetic anomaly have disclosed mercury in quantities up to 2,600 ppb. Mercury of this quantity has been used as an indicator of mineralization in nearby mining districts.

Welded tuffs in central Nevada

Ash-flow tuffs have been recognized and mapped over a large part of southern Lander County by E. H. McKee and J. H. Stewart. At least eight lithologically distinct units have been mapped. The youngest (25 m.y. by K-Ar dating) and most widespread tuff unit, which unconformably overlies all older rocks, has been mapped at present over 700 square miles and its limits have not been reached. Over most of the region it is less than 300 feet thick and is composed of 1 or 2 cooling units; locally it is more than 500 feet thick and contains as many as 3 and possibly 4 cooling units.

Pervasive structural trend across northern Nye County

Mapping in northern Nye County by F. J. Kleinhampl and J. I. Ziony suggests that over much of this region the structure is influenced by a deep-seated, pervasive structural grain which is older than the Basin-Range structure. This grain is reflected by interruptions in the north-trending mountain ranges and by numerous structural elements which trend at nearly right angles to the Basin-Range features; it may also have controlled mineralization in several mining districts, such as the Tybo silver district.

Bedrock profiles of western Nevada determined by gravity survey

Pahrump, Mesquite, and Ivanpah Valleys are located along the California-Nevada State line west and southwest of Las Vegas. All are fault-block valleys typical of the Basin and Range province. A gravity survey by R. G. Bates has made possible computation of one or more bedrock profiles across each valley. Vertical movement on the bounding faults ranges from 1,500 to 7,000 feet. Alluvium ranges from 3,500 feet in thickness in southern Ivanpah Valley to 9,000 feet in Pahrump Valley. A profile computed across Ivanpah Valley in the vicinity of Nipton shows a tilted fault block near the eastern end of the profile. The eastern fault roughly coincides with the McCullough fault, although the computed vertical movement of 7,000 feet is considerably less than the 20,000 feet previously determined from stratigraphic evidence. The fault bounding the western edge of the block agrees in direction and amount of vertical movement with the Road fault and may be its southward extension. Mesquite Valley has been considered a result of downwarping, and may have been so initially, but computed bedrock profiles show a central graben with vertical displacement of 6,000 feet.

Volcanic center in northern Kawich Range

Mapping in the northern Kawich Range, Nye County, by E. B. Ekren and C. L. Rogers has shown that the northern "bulbous" end of the range is a complex volcanic center and resurged caldera. Quartz-rich welded tuffs form the bulk of the outcrop in the range, followed in volume and age by lavas and intrusive masses of quartz-latite and rhyolitic compositions. Silver deposits at Silver Bow on the southwest flank and along the arcuate west flank of the range appear to be structurally controlled by the ring-fracture zone of the caldera.

Magnitude of strike-slip movements in southern Nevada

F. G. Poole has shown by offsets of facies and isopachs of Devonian strata in southern Nevada and southeastern California that strike-slip movements on the order of 30 miles have taken place on the Las Vegas shear zone and 50 miles on the Death Valley–Furnace Creek fault zone. These estimates accord with those by J. H. Stewart based on his study of upper Precambrian and Lower Combrian strata and by E. H. McKee in his study of offset granitic bodies north of Death Valley.

Northeast extension of Sierra Nevada granitic rocks

Geochemical study of granitic rocks in western Nevada by D. B. Tatlock and a series of K-Ar ages by R. F. Marvin suggest that the granitic basement underlying at least 3,000 square miles of western Pershing County is a northeastward extension of the Sierra Nevada batholith. K-Ar ages of about 90 m.y. have been determined from biotite-hornblende pairs in 6 samples of granodiorite from the Trinity, Antelope, Shawave, Selenite, and Granite Ranges. Statistical treatment of major elements in the chemical analyses shows that, for a given silica content, the granitic rocks of western Pershing County are indistinguishable from rocks of similar age in the eastern Sierra Nevada.

Periods of mineralization in Esmeralda County

Stratigraphic studies of Tertiary rocks in Esmeralda County by J. P. Albers, and radiometric age determinations carried out by Geological Survey colleagues show that mineralization occurred during at least three distinct intervals in the Tertiary. At Goldfield the K-Ar age of the altered and mineralized Milltown Andesite and overlying but unaltered welded tuff unit is 21 m.y., and the alteration and presumably the mineralization at Goldfield is assumed to be about 21 m.y. old. In the Divide district, 5 miles south of Tonopah, the mineralized Fraction Breccia is believed to be 17.5 m.y. old, based on a radiometric age determination of a sample of Fraction Breccia from the Kawich Range. A plug of unmineralized quartz latite that intrudes the Fraction Breccia has yielded a K-Ar age of 16.2 m.y. The age of mineralization in the Divide district thus appears to be between 16.2 and 17.5 m.y. In the Red Mountain district, Silver Peak Ridge, a porphyritic latite unit that is cut by numerous silver-bearing veins, is dated as 5.9 m.y. The silver-bearing veins in this district are therefore younger than 5.9 m.y.

UTAH

Structural interpretation of Precambrian and Paleozoic terrane in northwest Utah

R. R. Compton has mapped complexly thrust and folded Paleozoic and Precambrian rocks between the Raft River and Dove Creek Mountains, Box Elder County. The structure is visualized in terms of three elements, each with a different structural style. The lowest is a "basement" consisting of gneissic granite overlain by gently warped, strongly metamorphosed quartzite and schist that are, in part, Precambrian. The second element consists of folded, metamorphosed, and greatly thinned Paleozoic rocks that locally appear to be structurally continuous with the "basement" but in other places are clearly detached. All the rocks in this second plate exhibit well-defined lineations, have a strong directional fabric, are thrown into recumbent folds overturned to the east, and are cut by thrust faults rising from the basal plane of detachment. Four sets of folds can be recognized locally, but their regional significance and age have not yet been determined. The third structural element consists of unmetamorphosed rocks of the Oquirrh Formation of Pennsylvanian and Permian age. It is separated from both of the lower structural units by a widespread zone of detachment.

Volcanic-breccia feeder vents in Park City mining district

In the Park City mining district of central Utah, C. S. Bromfield has mapped several irregular-shaped volcanic breccias which crosscut about 800 feet of flat-lying volcanic breccias of the Keetley Volcanics of early Oligocene age. The intrusive breccias consist of angular to subangular fragments of porphyritic andesite in a matrix of comminuted rock of the same type. The volcanic intrusive breccias have steep contacts and tend to be elongated in a northeast direction. The largest is about ½ mile in maximum diameter, and 2 irregular dikes 100 to 500 feet wide extend northeast for about a mile. The intrusions probably represent feeder vents for some of the volcanic breccias which make up the great bulk of the volcanic field in this area.

Stratigraphic telescoping on thrust faults in central Utah

Analysis of Paleozoic rocks in the Stansbury Mountains by E. W. Tooker and R. J. Roberts shows that two different Devonian facies have been brought together by heretofore unrecognized thrust faults. A sedimentary sequence with basinward affinities characteristic of the Gold Hill district of western Utah has been thrust eastward over rocks characteristic of the Tintic district, central Utah. Stratigraphic evidence suggests that the western facies may have moved eastward as much as 40 miles.

Regional correlation of younger Precambrian rocks in central Utah

Younger Precambrian rocks described previously by M. D. Crittenden near Huntsville (*in* U.S. Geol. Survey, r0892, p. A84) are found to rest on tillite in a highly faulted area about 3 miles south of Brigham City. Though unnamed, these tillites are presumably correlative with tillites exposed in Mineral Fork in the Cottonwood area, in the Sheeprock Range, at Little Mountain, and elsewhere in Utah and in the Pocatello area of Idaho. Reconnaissance mapping also reveals a marked northwestward increase in the percentage of intertonguing volcanic rocks, which has suggested to R. G. Yates that the rocks of the Huntsville section may be correlative with part of the Windermere Group in British Columbia where volcanics are also associated with anomalous "conglomerates." This evidence provides the first substantive clue to the regional correlation of the post-tillite rocks in Utah and Idaho with the Windermere Group, and of the pre-tillite rocks (Big Cottonwood Formation) with the Belt Series of Idaho and Montana.

ARIZONA

Shylock fault zone a Precambrian structure

The major north-trending Shylock fault zone, 17 miles east of Prescott, is interpreted by C. A. Anderson (p. C60–C65) as a Precambrian zone of right-lateral strike slip, with a minimum displacement of 5 miles.

Age of two intrusive rocks in Pinal County

M. H. Krieger reports that muscovite granite that intrudes older Precambrian quartz monzonite (Oracle Granite of Peterson, 1938)[54] in northeastern Pinal County yielded a K-Ar age for muscovite of 1,310 m.y., and an Rb-Sr whole-rock age of 1,550 m.y. Both the muscovite granite and its host are thus shown to be older Precambrian. Biotite from porphyritic granodiorite similar to the porphyry dikes in the San Manuel mine area yielded a K-Ar age of 66 m.y., showing the granodiorite to be early Tertiary or Late Cretaceous.

Local structural high in southeast Arizona

T. L. Finnell, working in the Empire Mountains of southeast Arizona, has shown that Lower(?) Cretaceous sandy limestones lap unconformably onto Precam-

[54] N. P. Peterson, 1938, Geology and ore deposits of the Mammoth mining camp area, Pinal County, Arizona: Arizona Bur. Mines Bull. 144, Geol. Ser. 11 (Univ. Bull. v. 9, no. 2), 63 p.

brian(?) schist, gneiss, and granitoid rocks. He believes these rocks were part of a local tectonic block some 2 miles wide and 4 miles long that was actively shedding debris during much of Early Cretaceous time. About 7 miles to the south, limestone beds that are probably equivalent to those of the Empire Mountains are underlain by at least 4,800 feet of Cretaceous strata that in turn overlie about 6,000 feet of Paleozoic strata, indicating a total structural relief of nearly 11,000 feet.

Linear structures in western Arizona

Several straight, northwest-striking topographic lineaments in the southern Plomosa Mountains have been found by F. K. Miller to mark right-lateral strike-slip faults. Offset of steeply dipping sedimentary contacts suggests displacements of as much as 3 miles. One such fault projects northwest into a similar fault in the Dome Rock Mountains. Similar lineaments in other ranges in southwestern Arizona suggest that such faults may be widespread regional features.

Laramide tectonics of southern Arizona

As a result of his studies in the Mount Wrightson quadrangle, Harald Drewes believes he can recognize a close temporal and spatial relation between plutonism, volcanism, and glide faulting of Laramide age. (1) Crustal shortening involved in a belt of tightly folded Lower Cretaceous rocks is approximately that required to provide space for the adjoining belt of Laramide plutons. (2) Volcanics and plutons show close chemical affinities, and are shown by K-Ar ages to be closely related in time. (3) Plates of Paleozoic rock suspected to have formed the roof of the plutons slid westward off a rising welt, and overrode Upper Cretaceous red beds; they provided a source for giant exotic blocks enclosed in volcanics, and are overlapped by latest(?) Cretaceous volcanics. Tectonic gliding and volcanism are thus contemporaneous, and are regarded as surficial aspects of the Laramide orogeny that involved emplacement of plutons at depth.

History of Tucson Basin

E. F. Pashley, Jr., reports that geologic features in the northern half of the Tucson Basin, south-central Arizona, indicate a fairly complete record of the Cenozoic evolution. The Santa Catalina, Tanque Verde, and Rincon Mountains were uplifted in Late Cretaceous to middle Tertiary times, and their internal structure was formed—a series of broad west-southwest-trending and plunging folds in layered granitic gneiss. Configuration of these folds profoundly affected relief within the mountains, position of major drainageways, patterns of erosion and deposition, and the shape of the basin. Unnamed Tertiary beds exposed on the piedmont record in their varying pebble compositions the gradual uplift and erosion of the mountains. The composition of the oldest part of the unnamed beds reflects the early stages of uplift, when mountain gneissic cores were mainly covered by quartzite, limestone, and volcanic rocks. The composition of beds of intermediate age records further uplift and exposure of gneissic cores. The youngest beds are composed mainly of gneiss fragments and were deposited after the basins and ranges reached their present configuration.

The close of deposition of these beds was marked by normal faulting within the piedmont area. This faulting broke these beds into a series of tilted blocks but did not extend into the gneissic rocks. Erosion during and after the faulting truncated the unnamed Tertiary beds, destroyed fault-block topography, and formed a surface or pediment. The surface then was buried by alluvial fans, which extended to the center of the basin. During middle and late Quaternary time, streams cut the alluvial fans and transported debris from the basin. Also, Rillito Creek was established slightly south of its present position. Three cycles of northward migration and downcutting of Rillito Creek are preserved in terraces on the south bank and a steep erosional scarp along the north bank.

CALIFORNIA

Recumbent folding in northern Inyo Mountains

A large anticlinal fold, in part recumbent, spans the northern Inyo Mountains and has been mapped by D. C. Ross. Thrust sheets of the distended upper limb, generally in stratigraphic order, have ridden onto overturned beds of the lower limb that have been rotated as much as 180°. The sole of one of the upper limb thrusts can be traced into a normal stratigraphic contact. The folding and thrusting probably predate the period of granitic intrusion, as one of the large Jurassic plutons of the area has intruded the overturned limb of the fold. The shape of part of the fold has been modified by injection of the pluton.

Stratigraphy of northern White Mountains

D. F. Crowder has mapped two sequences of rocks of unknown age in the White Mountain Peak quadrangle of eastern California. The lower sequence consists of conglomerate, siltstone, and sandstone, and is separated from the upper sequence by an angular unconformity. The upper sequence consists of metavolcanic rocks, graywacke, and conglomerate. Both sequences are unfossiliferous. They are unlike dated lower Paleozoic strata to the south and are separated from them by a granodiorite pluton.

K-Ar ages in central White-Inyo Mountains

K-Ar ages by E. H. McKee and D. B. Nash (r1846) of hornblende and biotite from granitic rocks in the central White-Inyo Mountains indicate that the composite Inyo batholith was emplaced in Early to Middle Jurassic time (184–151 m.y.) and contains a small, possibly xenolithic, body of foliated granodiorite of Triassic age (213 m.y.). Two isolated plutons were emplaced in the metamorphic rocks west of the batholith in the Cretaceous (77–80 m.y. and 130–138 m.y.). The age groups of the intrusive rocks in the White-Inyo Mountains are similar to those of the Sierra Nevada and support the concept that the Inyo and Sierra batholiths are comagmatic.

Age of Searles Lake levels

Geologic mapping of upper Quaternary deposits in the north part of Searles Valley by G. I. Smith has provided a record of the levels reached during the last four high stands of the lakes that occupied the valley during middle and late Wisconsin time. These stands were separated by periods of relative aridity which caused the lakes to recede and are tentatively correlated with deposits elsewhere in the valley that are dated by the carbon-14 method. The following pluvial history is inferred: About 25,000 years ago the lake rose to the 2,000-foot level, which is about 480 feet above the present valley floor. After a recession, but before 14,000 years ago, the lake again rose to 2,280 feet, the level of the spillway for Searles Valley. About 12,000 years ago the lake rose to 2,040 feet for a short time, and, after a short recession, rose again to the 2,280 spillway level. By 10,500 years ago the lake had become a relatively small saline body in the center of the valley. These lake-level fluctuations were controlled by climatic changes which probably affected large areas, and thus the record provides a regional history of late Pleistocene climates.

Mineralized Miocene sequence in central Mojave Desert

Geologic mapping of the Calico Mountains north of Daggett by T. W. Dibblee, Jr., has delineated a sequence of Miocene volcanic rocks overlain by Miocene continental sediments totaling more than 7,000 feet in thickness. The volcanic rocks consist of andesite flows, breccias, and tuff breccias. Both volcanic and sedimentary rocks are mineralized with veins of barite, quartz, and jasper containing silver, gold, copper, and zinc. The rich pockets of silver have been mined out, but rare disseminated silver and gold are present in brecciated zones.

COLUMBIA PLATEAU AND SNAKE RIVER PLAIN

OREGON

Dalles–Umatilla syncline, Oregon and Washington

In a recent article (p. B88–B93) R. C. Newcomb has summarized the structure of the Dalles-Umatilla syncline, a 160-mile-long fold that parallels the Columbia River from the east slope of the Cascades to Umatilla, north-central Oregon, then diverges toward the upper part of the Umatilla River. In the syncline, basalt of the Columbia River Group is warped down 2,000 to 4,000 feet below the bordering uplifts. The western part of the syncline is asymmetric; the north limb is steeper. The eastern part is symmetrical, but uplift of the southern limb is greater.

Moraines at Wallowa Lake

The compound morainal embankments that enclose Wallowa Lake, northeastern Oregon, include the deposits of at least four glaciations, according to a recent article by D. R. Crandell (p. C145–C153). Differentiation of drift units is largely based on conspicuous differences in the depth of oxidation and the relative amount of secondary clay and calcium carbonate in weathering profiles, and on the presence or absence of granodiorite boulders on moraines. The youngest two drifts are assigned to the Fraser and Salmon Springs Glaciations, the oldest two are probably pre-Sangamon.

PACIFIC COAST REGION

WASHINGTON

K-Ar ages of plutons in Northern Cascade Mountains

The ages of the plutons in the Northern Cascade Mountains are being studied by J. C. Engels in cooperation with F. W. Cater and others (r2100). In the metamorphic terrane between Glacier Peak and Lake Chelan, northern Washington, biotite and concordant biotite-hornblende and biotite-muscovite ages of 5 plutons indicate crystallization 62, 57, 45 (2 plutons), and 22 m.y. ago. A concordant biotite-hornblende age for a pluton intruding unmetamorphosed Cretaceous rocks in the Pasayten area is 86 m.y. These ages agree with relative ages of intrusion insofar as they can be determined.

Similar K-Ar ages of plutons have been reported from elsewhere in the Northern Cascades; some, however, are as young as 13 m.y. It appears that recurrent and broadly related intrusions have been adding material to the core of the Northern Cascades from the Late Cretaceous at least to the late Miocene. Quaternary volcanism suggests that it may be going on today.

Two ages of mineralization in Glacier Peak–Lake Chelan area

Recent radiometric dating of samples collected by F. W. Cater has established two periods of mineralization in the Glacier Peak–Lake Chelan area of northern Washington. The Holden copper, zinc, and gold deposits are dated at 43 m.y., and are probably related to adjacent intrusives of about the same age. The Glacier Peak copper-molybdenum deposits are in and related to the Cloudy Pass batholith, which is dated at 22 m.y.

Post-Triassic unconformity in northern Okanogan County

In granitic and metamorphic terrane east of the Cascades, K. F. Fox, Jr., and C. D. Rinehart have found an unconformity above which greenstone is less deformed and of lower metamorphic grade than underlying greenstone and epiclastic rocks. This relationship suggests two periods of metamorphism. Conglomerates in the upper part of the younger unit contain fragments of the older metamorphic rocks. Geochronologic data suggest that the older period is Late Triassic, but the age of the younger period is not yet known.

Composition of Pleistocene clays in Seattle area

Unweathered glaciolacustrine and glaciomarine clays of relatively uniform composition are the principal clay deposits in the Seattle area, western Washington, according to a recent article by D. R. Mullineaux (p. B69–B76). Their prominent clay minerals, in order of abundance, are chlorite, illite, and montmorillonite, and they are saturated with exchangeable calcium and magnesium cations. Nonglacial and weathered glacial clays are more variable in composition and of smaller volume. Typically they contain a higher proportion of montmorillonite, and may also contain kaolinite and vermiculite.

Miocene basalt units in southwestern Washington

Mapping by E. W. Wolfe and E. H. McKee in the Grays River quadrangle has distinguished two units of Miocene basalt flows. The basalt units can be distinguished by chemical analysis, and the difference in chemistry is readily seen in the refractive indices of fused beads. The two units show a definite similarity to two of the Miocene flow units recognized by P. D. Snavely, Jr., in western Oregon and Washington and to the Yakima and late Yakima petrographic types of A. C. Waters in the Columbia Plateau. Intrusive equivalents of both units, as well as the Pomona flow (part of the Yakima Basalt) of the Columbia Plateau, are found in the Grays River area.

OREGON

Gabbros and lamprophyres in northern Coast Range

Mapping in the Saddleback Mountain area in Lincoln County by P. D. Snavely, Jr., and others [55] indicates the presence of three suites of gabbroic rocks and lamprophyres of different ages. The oldest gabbro suite forms numerous sills which were emplaced during the late Eocene into the Tyee and Yamhill Formations. These sills are highly altered and some are albitized. Porphyritic basalt sills and dikes of probable late Eocene or earliest Oligocene age cut the older gabbroic rocks. During the early(?) Oligocene, camptonite sills and dikes were emplaced, and during the middle Oligocene, sills of gabbro, granophyric ferrogabbro, and ferrogabbro were intruded. These sills are similar to those farther south in the Oregon Coast Range [56] and to major dolerite sills in other regions such as the Karoo dolerites (South Africa) and Ferrar dolerites (Antarctica). Age of faulting in the Coast Range can be determined by the displacement of the gabbro suites of different ages.

Laminar-flow structures in welded tuff on Wagontire Mountain

G. W. Walker has mapped a soda-rhyolite tuff on the south slope of Wagontire Mountain, in Lake and Harney Counties, that has undergone laminar flowage (Walker and D. A. Swanson, r1786). Platy flow-jointing, stretched pumice lapilli, and asymmetric ramp structures show that flowage has taken place and point to two vents at opposite ends of the mountain. Cause of flowage may be deposition on steep slopes at high temperature or the fluidizing effect of a high content of soda and iron in the tuff.

CALIFORNIA

Inverted metamorphic zonation in northern Coast Ranges

Studies by M. C. Blake, Jr., and others (p. C1–C9) show that a narrow belt of blueschist-facies rocks extends for more than 300 miles in rocks of the Franciscan Formation along the eastern boundary of the Coast Ranges in California and Oregon. The blueschist rocks commonly are separated from rocks of adjacent provinces to the east by ultramafic rocks along a regional east-dipping thrust fault. Grade of meta-

[55] P. D. Snavely, Jr., E. M. Baldwin, M. S. MacLeod, A. E. Roberts, and H. C. Wagner, in press, Differentiated Oligocene gabbroic sills in the Oregon Coast Range, Oregon: Oregon Dept. Geology and Mineral Industries Bull.

[56] P. D. Snavely, Jr., and H. C. Wagner, 1961, Differentiated gabbroic sills and associated alkalic rocks in the central part of the Oregon Coast Range, Oregon: Art. 344 *in* U.S. Geol. Survey Prof. Paper 424–D, p. D156–D161.

morphism within the blueschist belt increases toward the fault. Reconstitution of metagraywacke forms zones that correspond texturally to the chlorite subzones 1, 2, and 3. The transition from pumpellyite to lawsonite occurs at the boundary between textural zones 1 and 2. Folding increases in intensity toward the thrust fault, and is isoclinal in textural zone 3. The blueschist-facies rocks are thought to have formed in a zone of high water pressure along the sole of the thrust fault, resulting in the inverted metamorphic zonation.

Structure of Burro Mountain ultramafic body

Study of the Burro Mountain ultramafic body, southern Santa Lucia Range, Monterey County, by R. A. Loney, G. R. Himmelberg, and N. J Page has shown it to be bounded by curving shear zones which are generally confined to the ultramafic rock. The northeast contact is the Nacimiento fault; other regional faults cut across the body and locally fault-in masses of graywacke.

The body consists mainly of peridotite, which has north-striking subvertical layering and is cut by veins and irregular masses of dunite with weak planar structures parallel to the peridotite layering. Shear zones are largely serpentinite.

Paleogeographic data from Miocene basalts, southern Coast Ranges

H. E. Clifton has studied three basalt flows interbedded with marine-nonmarine transitional deposits of middle Miocene age in the southeastern Caliente Range, southwestern California (p. B32–B39). A source area for the middle and lower basalts near the west fork of Padrones Canyon is indicated by the presence there of: (1) the thickest parts of the flows, (2) subjacent basalt dikes, and (3) volcanic sandstone and other pyroclastic materials. Inclined amygdules indicate flowage to the west and southwest. Paleocurrent data from an overlying fluviatile sandstone also suggest a west-southwest paleoslope. The lower basalt flow is subaerial throughout, but the middle flow contains pillows, braccia, and geodes near its northwestern terminus, suggesting that it there flowed into the sea.

Volcanic-plutonic relationships in northern Sierra Nevada

Anna Hietanen-Makela has mapped two distinct groups of plutonic rocks in the Bucks Lake quadrangle. The older group, of probable Jurassic age, ranges from gabbro to quartz diorite and tonalite and intrudes andesitic and dacitic volcanic rocks. Both plutonic and volcanic rocks are deformed and metamorphosed to the albite-epidote-amphibolite facies. The close association of these intrusive and volcanic rocks of similar composition suggests that they are comagmatic.

The younger group of plutonic rocks, of probable Cretaceous age, ranges from hornblende gabbro to tonalite and tronhjemite. They are typical Sierran coarse-grained unmetamorphosed rocks.

"Dinkey Creek" type granodiorite in central Sierra Nevada

Mapping in the Huntington Lake quadrangle by P. C. Bateman has shown that a plutonic unit mapped in reconnaissance as hornblende-biotite granodiorite, "Dinkey Creek" type (Krauskopf), includes several plutons. The most widespread rock is granodiorite which is continuous with granodiorite exposed in the Dinkey Creek area and is the host for several younger and more felsic plutons. Presumably they are differentiated from the "Dinkey Creek" and constitute a magmatic series with it.

ALASKA

During the past year, geologic mapping, geophysical and paleontological findings, and geochemical, glacial, and earthquake research were carried out in all the major regional subdivisions of the State. This work has resulted in a number of new scientific discoveries of significance which are summarized below. Figure 4 is an index map showing the boundaries of the regions referred to in the summary.

NORTHERN ALASKA

Gravity data in northwestern Alaska

Surveys and compilation of a gravity map of Alaska are being continued by D. F. Barnes especially in northwestern Alaska, where new information concerning the continuity of the Brooks Range structures was obtained. The low gravity values associated with the Colville geosyncline north of the range increase toward the west and suggest a significantly thinner sedimentary section south of Point Lay. The gravity lows in the central part of the range continue beyond its westernmost peaks but probably indicate local intrusive bodies and small sedimentary basins. The belt of gravity highs on the south flank of the range continues west of Bettles and passes through the Selawik Basin, thus militating against the presence of the sedimentary basin postulated in preliminary petroleum investigations.

Pre-Wisconsin glaciation, Seward Peninsula

In a report by C. L. Sainsbury (p. D203–D213) evidence for pre-Wisconsin glaciation is recognized

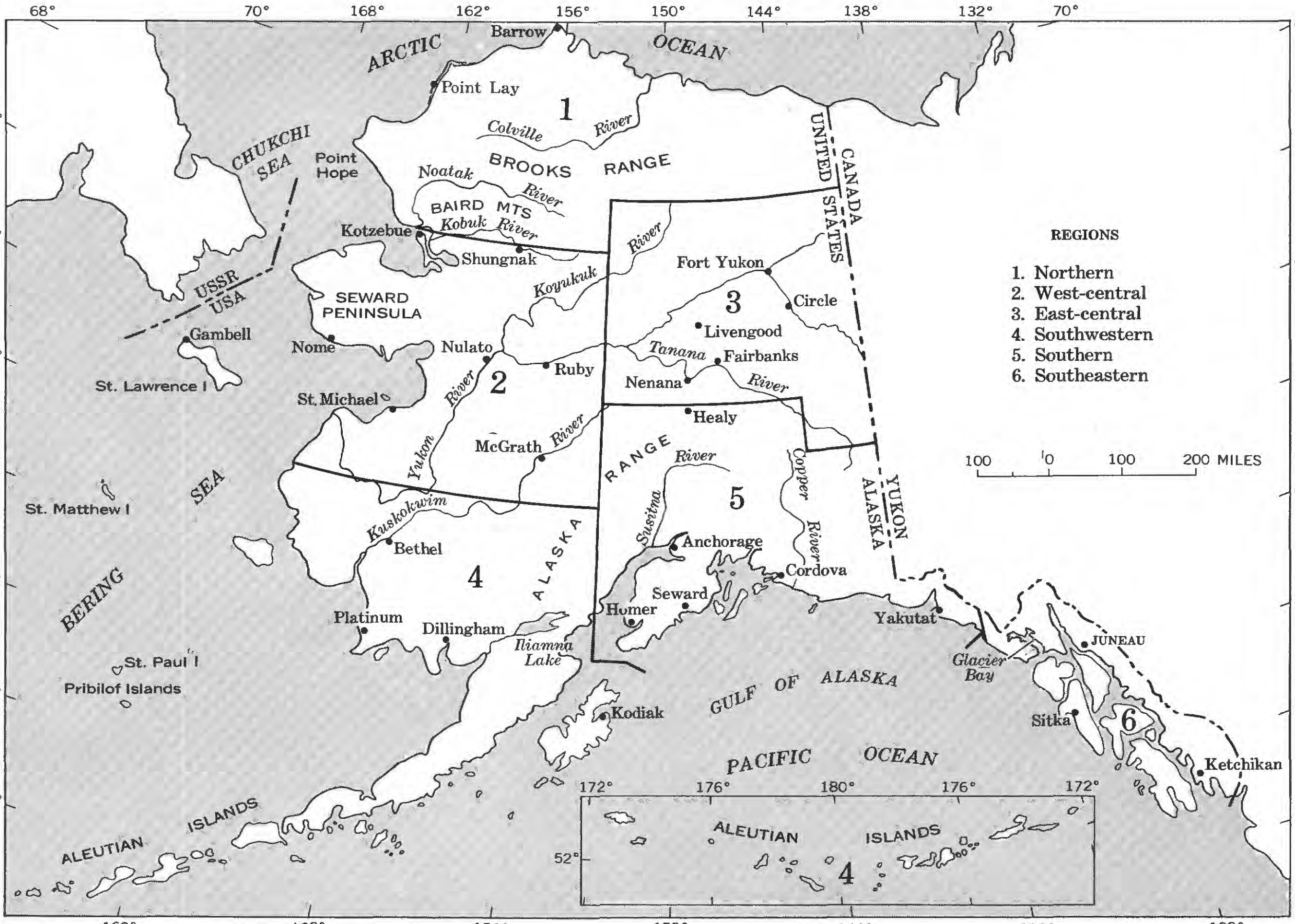

FIGURE 4. Index map of Alaska, showing boundaries of regions referred to in discussion of Alaskan geology.

for the first time on the Alaskan side of Bering Strait. The east limit of the York Glaciation of early Wisconsin age is defined by terminal moraines and by preservation of unglaciated marine deposits on the Lost River terrace of Sangamon age. The maximum northwest extent of Wisconsin ice from the Kigluaik Mountains is also defined by these marine deposits. A refinement of existing correlations is proposed, and an anomalous glacial pattern is shown by the fact that Wisconsin glaciers extended as far or farther on the north side of the low York Mountain as they did on the north side of the Kigluaik Mountains, a much higher range some 50 miles to the east.

Carbon-14 dates show that some peat bogs were formed on the Seward Peninsula 10,000 years ago, and that the barrier bar along the northwest coast of the Seward Peninsula is migrating rapidly landward. The local destruction of the York terrace of Yarmouth(?) age, and the Lost River terrace of Sangamon age, can be explained by glaciation and by dune migration.

WEST-CENTRAL ALASKA

Three marine terraces on St. Lawrence Island

D. S. McCulloch reports that fieldwork on Quaternary features of St. Lawrence Island has delineated three elevated marine wave-cut terraces. Magnetic-polarity measurements of volcanic rocks cut by these terraces indicate that all the terraces are less than 750,000 years old. The lowest terrace, of probable Sangamon age, has yielded a marine molluscan fauna, as yet unidentified and undated; the intermediate terrace, probably 175,000 years old, has yielded only a few shell fragments; no fossils were found on the uppermost terrace.

Repetitive alternation of alkalic and tholeiitic basalts

Reconnaissance examination by J. M. Hoare and W. H. Condon of the continental volcanic rocks of Quaternary and late Tertiary age on Nunivak and St. Lawrence Islands, in the Ingakslugwak Hills, and in the St. Michael area, reveals that both highly alkalic basalt and tholeiitic basalt are present in all four areas. Field mapping, paleomagnetic data, and K-Ar dating (Nunivak Island only) show that there has been a repetitive alternation of alkalic basalt with large outpourings of tholeiitic basalt. On Nunivak Island this pattern of volcanism has lasted at least 6 m.y. The close association of the two kinds of basalt in space and time suggests a common origin.

Unusual occurrence of alkalic subsilicic complexes

Investigations in the Shungnak-Selawik quadrangles of west-central Alaska by W. W. Patton, Jr., and T. P. Miller have shown the occurrence of a belt of alkalic subsilicic complexes of mid-Cretaceous age. There are 4 complexes ranging in area from 6 to 20 square miles and a belt of nepheline syenite intrusive rocks cutting the Selawik Hills pluton. Rock types in these complexes include leucocratic to melanocratic varieties of nepheline syenite such as: borolanite, malignite, foyaite, ijolite, shonkinite, pyroxenite, tinguaite, pulaskite, and grennaite. Essential minerals are alkali feldspar, nepheline, pyroxene, biotite, melanite, and hornblende. Accessory minerals and alteration products include sphene, apatite, magnetite, pyrite, zircon, eudialyite, fluorite, perovskite(?), cancrinite, sodalite, and zeolite. These complexes underlie low glaciated hills along the southern edge of the Selawik lowland. The setting for these alkalic subsilicic complexes is unusual in that they do not occur in a stable platform as do most complexes of this type, but were intruded into a tectonically active eugeosynclinal belt.

Overthrusting in western Baird Mountains

Large-scale overthrusting of Devonian carbonate rocks over coeval Devonian clastic rocks occurred in a 35-mile-long south-southwest-plunging anticline in the western Baird Mountains, according to W. P. Brosgé, H. N. Reiser, and I. L. Tailleur. Rocks in the core of this anticline are shale and sandstone and are correlated with the Upper Devonian Hunt Fork Shale and the Devonian and Mississippian Noatak Sandstone. The core rocks of the anticline are locally overlain by remnants of the Mississippian Kayak Shale and fossiliferous Mississippian limestone of the Lisburne Group. The overlying rocks on both flanks of the anticline are coralline Middle(?) and Upper(?) Devonian limestone and dolomite that have been thrust over the Devonian clastic rocks. On the west flank of the anticline, fossiliferous Mississippian limestone of the Lisburne Group rests directly on the Devonian carbonates of the thrust plate; Upper Devonian and Lower Mississippian clastic rocks are absent in this thrust-plate sequence. Similar Devonian carbonate rocks thrust over the east flank of the anticline form a broad synclinorium in which no post-Devonian rocks were recognized. These Devonian carbonate rocks may intertongue eastward with only minor fault displacement into a sequence of interbedded limestone and clastic rocks or they may be allochthonous with respect to this interbedded sequence.

EAST-CENTRAL ALASKA

Palynological evidence for age of Nation River Formation

A report by R. A. Scott and L. I. Doher (p. B45–B49) questions, on paleontologic grounds, the age of the Nation River Formation, previously considered to be of Pennsylvania or Early Permian age. A collection of fossil spores from the upper part of the formation shows it to be much older, probably Late Devonian in age. Forms included in more than 20 genera of spores have been recognized in the 3 samples studied, despite certain deficiencies in preservation. The most outstanding feature in the assemblage is the presence of spores with prominent spines having bifurcate tips (*Hystricosporites* McGregor and *Ancyrospora* Richardson). This is a consistent feature of Middle and Late Devonian spore assemblages from widely distributed areas.

Serpentinized ultramafic rocks in vicinity of Clinton Creek, Canada

Several small outcrops of serpentinized ultramafic rock south of previously known ultramafic bodies were discovered in the course of reconnaissance geologic mapping of the Eagle B-1 and C-1 quadrangles in east-central Alaska by H. L. Foster. The easternmost outcrops are a few miles east of a large asbestos deposit on Clinton Creek in Canada, which is currently being mined. The geology of these two areas appears to be similar.

SOUTHWESTERN ALASKA

Three distinct intrusive phases in Iliamna quadrangle

R. L. Detterman and B. L. Reed have discovered that three distinct phases of intrusion have occurred within the Iliamna quadrangle. The ages of these phases are middle Tertiary, Late Cretaceous (70–90 m.y.), and Middle Jurassic (165–170 m.y., average). Although the Tertiary intrusive rocks have not yet been dated isotopically, the age can be determined by its relationship to Tertiary extrusive and sedimentary rocks. Most of the mineralization in the quadrangle is associated with the Tertiary phase of igneous activity.

Structure of Kodiak Island

Kodiak Island has been represented on geologic maps as a faulted syncline. New mapping by G. W. Moore, however, has shown that the major structure of this large island is an asymmetrical anticline. Cretaceous rocks on the northwest side of the axis of the anticline dip about 45° NW.; southeast of the anticlinal axis, these Cretaceous rocks and overlying lower Tertiary rocks are approximately vertical.

SOUTHEASTERN ALASKA

Gabbroid rocks formed by thermal metamorphism of greenstone in Haines area

Gabbroid rocks and amphibole metabasalt or greenstone in the Haines area are petrographically and chemically similar rocks, despite great differences in grain size and appearance, reports E. C. Robertson. The gabbroid rock is a screen between the tonalite of the Coast Range batholith and the greenstone. The mode of the gabbroid rock is about 39 percent amphibole, 47 percent labradorite, and 14 percent minor minerals. The greenstone contains 64 percent amphibole, 29 percent oligoclase, and 7 percent minor minerals. By calculation from the chemical analyses, both the gabbroid rock and the greenstone have a mafic norm of 43 percent pyroxene, 46 percent andesine, and 11 percent minor minerals. Apparently the gabbroid rocks were formed from greenstone by thermal changes associated with the emplacement of the batholith.

Quaternary emergence of Mendenhall Valley

The last Pleistocene (Wisconsin?) ice sheet began to melt about 17,000 years ago in the vicinity of the Mendenhall Valley, which is about 10 miles northwest of the city of Juneau. The valley was probably free of glacial ice as far north in the valley as the present front of the Mendenhall Glacier by 11,000 to 7,500 years ago, according to a study by W. W. Barnwell and C. W. Boning. The valley area subsided 500 to 700 feet during maximum glaciation and was filled by sea water as the ice retreated. The land surface began to rise as the ice melted. By 4000 to 5000 B.C., sea and land levels probably were within 15 feet of their present elevations and have remained so since that time. The sedimentary environment in the low-lying valley floor has consequently regressed from marine to nonmarine conditions over approximately the last 7,000 years. The Mendenhall Glacier probably began to re-advance about 1000 B.C. and reached its farthest advance prior to A.D. 1750. Since then, it has receded at an average annual rate of 40 feet per year.

Late Pleistocene marine submergence of Juneau area

A landslide studied by R. D. Miller on the Mansfield Peninsula of Admiralty Island, about 16 miles west of Juneau, has exposed an upper Pleistocene stony, clayey silt that contains marine mollusks. The silt extends to a height of 735 feet above sea level, indicating that the Juneau area was submerged to a depth of more than 735 feet, which is 200 feet deeper than was previously recognized. It is not yet known whether the subsequent uplift of the area was caused by postglacial isostatic rebound, by tectonic warping or faulting, or by a combination of both causes.

Floors of enclosed basins are approximately level and planar, with less than 10 feet of relief in transverse profiles and longitudinal slopes of less than 1:100. The basin floors are sedimentary surfaces that have developed from rapid infilling after deglaciation. Comparison between soundings in 1966 and soundings in 1936 and 1940 indicates that sedimentation is continuing. Sedimentation rates range from 0.4 to 4.2 feet per year and are comparable to those of similar settings elsewhere in southeastern Alaska. The highest sedimentation rates are found in the most recently deglaciated basins, probably because the sediment supply decreases as glaciers recede, vegetation develops, and deltas form.

New structural and stratigraphic evidence in Glacier Bay National Monument

Reconnaissance geologic mapping in Glacier Bay National Monument by D. A. Brew, C. C. Hawley, A. T. Ovenshine, and A. B. Ford, and compilation of previously mapped contiguous areas, have led to improved geologic understanding of a large and hitherto poorly known area. New stratigraphic information obtained includes fossil, lithic, and facies-change data from a very thick section of Silurian through Middle Devonian graywackes, shales, and limestones in the eastern half, and the recognition of metamorphosed Triassic(?) and Jurassic-Cretaceous volcanics, graywackes, and shales in the western half of the monument. Significant new structural data show that the north-northwest regional trends are abruptly interrupted by east-trending fold and fault zones in the northeastern part of the monument. Study of the intrusive bodies indicates that most occur in three distinct belts. A north-trending westernmost belt contains the Tertiary (?) layered gabbroic complexes of the Fairweather Range, and adjacent to it on the east is a belt of mixed Tertiary(?) leucocratic unfoliated silicic granitic rocks and Jurassic-Cretaceous(?) foliated intermediate granitic rocks. A west-northwest-trending belt of similar foliated intrusions joins the north-trending belt in the north-central part of Glacier Bay Monument.

Thick and unmetamorphosed Paleozoic section

A 2-year field investigation in the Craig-Klawak area by G. D. Eberlein and Michael Churkin, Jr., is now completed and, along with previous work in the Heceta-Tuxekan area to the north, indicates that the area contains one of the thickest unmetamorphosed Paleozoic sections in Alaska, and possibly in North America. The present work, as supplemented by paleontologic data, has extended the known age span of the rocks through all times from the Early Ordovician Epoch into the Permian Period, and has filled in many gaps in the biostratigraphic record.

New geologic data from Annette Island

Early results of fieldwork on Annette Island by H. C. Berg include the discovery of *Heterasteridium* sp. in a complexly folded thin-bedded limestone and slate outcrop near Driest Point. The fossil definitely establishes the age of a section of rocks, heretofore mapped as Devonian, Triassic, or Jurassic-Cretaceous, as late Late Triassic.

At Yellow Hill, where previous reports indicate deposits of serpentine with negligible amounts of unaltered ultramafic rock, appreciable fresh peridotite was found. Berg discovered that the Yellow Hill pluton is partly in fault contact with the enclosing rocks, suggesting tectonic rather than magmatic emplacement. There appears to be no obvious thermal effect on the enclosing rocks, which are mainly amphibolite and quartzofeldspathic schist, but the possibility of low-temperature calcium metasomatism is not ruled out.

PUERTO RICO

Volcanic rock of Río Orocovis Group

According to A. E. Nelson (r0643, r0272), rocks of the Cretaceous Río Orocovis Group in the Corozal quadrangle of north-central Puerto Rico consist chiefly of andesitic and basaltic tuffs, breccias, and lavas whose compositions suggest differentiation from a fundamental tholeiitic magma. The gross stratigraphic gradation is from basalt upward into andesite, but andesitic lava lenses are intercalated in predominantly basalt sections, basalt is similarly intercalated in predominantly andesitic terrane, rocks of intermediate composition are common, and basaltic crystal-vitric tuff occupies a large part of the overall section.

Synorogenic plutonism

Geologic mapping in west-central Puerto Rico by P. H. Mattson (r0645) has shown that Eocene clastic and volcanic rocks of the Jacaguas Group rest unconformably on plutonic rocks associated with the Utuado batholith and on Cretaceous volcanic rocks. Mattson concludes that the unconformity is of epochal (10–20 m.y.) significance within the Antillean Orogeny, and that it demonstrates that synorogenic plutons may be exposed during rapid deformation, uplift, and erosion in an orogenic belt.

Long-lived drainage patterns

Studies in north-central Puerto Rico by W. H. Monroe (r0644) suggest that present courses of the Río Grande de Manatí and Río Mavilla in pre-Oligocene rocks are in fact relics of river patterns during Oligocene and Miocene time. Sand members of the Oligocene to lower Miocene Cibao Formation and facies in the lower Miocene Aguada Limestone were deposited following erosion and transportation in the ancient drainage system.

Widespread laterized lag deposits in karst terrain

About 400 sq km of 16- by 126-km band that parallels the north coast of Puerto Rico is underlain by sand deposits averaging more than 4 m in thickness. Early suggestions that these blanket sands were residual from limestone are not tenable because of the great purity of the limestone in which they are entrapped. The hydrology of the area also precludes an artesian-spring origin for the purest quartz sands. The presence of high-temperature quartz crystals also rules out an hypothesis of authigenic development of the quartz in the clay, and the high elevation and position of some of the deposits make a completely Quaternary origin unlikely. The blanket sands are believed to range from Miocene to Recent in age.

According to R. P. Briggs (r1735), these blanket sands are composed chiefly of quartz sand and reddish-brown clay. They were derived initially from volcanic and plutonic rocks in the highlands of Puerto Rico and were deposited as longshore sands on the middle Tertiary limestone of the area. Uplift of the limestone stranded the sands. Surface drainage on this permeable terrane was minimal; consequently, the sands were not eroded away. Rather, they were entrapped in a developing karst topography and concurrently were laterized.

Porphyry copper mineralization

M. H. Pease, Jr. (r0642) reports that most disseminated copper deposits in Puerto Rico occur in elongate bodies of altered "orthoclase" quartz-diorite porphyry along or within major west-northwest-trending shear zones and commonly adjoining or closely associated with larger granitic-textured plutons. Reddish-brown finely divided hydrothermal biotite is commonly associated with the sulfides, which are chiefly pyrite and chalcopyrite.

ANTARCTICA

Fieldwork by the U.S. Geological Survey in Antarctica during the 1966–67 austral season was continued by J. M. Schopf. Geological, geophysical, and paleontological topical studies of areas in the Transantarctic Mountains (fig. 5) were conducted in the laboratories and offices of the Geological Survey. These investigations are part of the U.S. Antarctic Research Program, supported and coordinated by the U.S. National Science Foundation and with fieldwork logistically supported by the U.S. Navy Operation Deep Freeze. Topographic and planimetric maps are compiled by and aerial photography is provided by the Topographic Division of the Geological Survey (see section "Topographic Surveys and Mapping, Mapping in Antarctica").

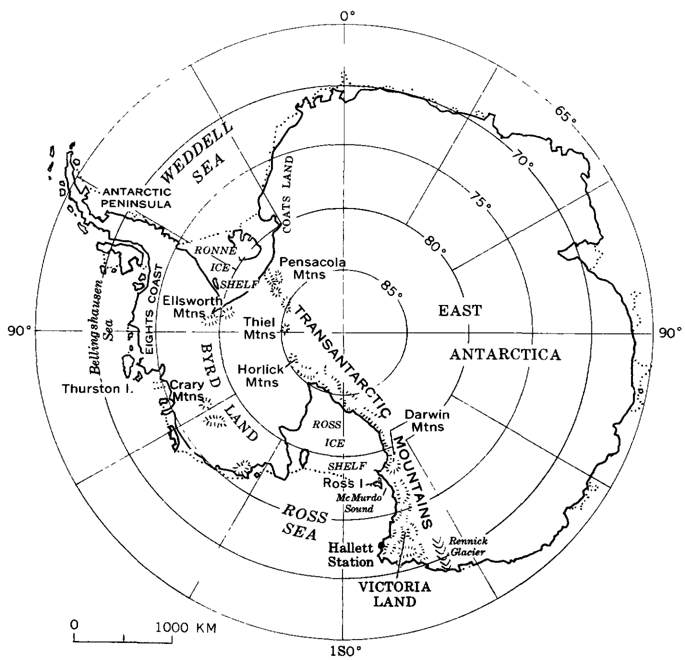

FIGURE 5. Index map of Antarctica.

Magmatic differentiation of Dufek stratiform intrusion

The large stratiform intrusion of post-Permian age in the northern part of the Pensacola Mountains consists of rhythmically layered pyroxene gabbros containing infrequent layers of anorthosite and pyroxenite and a capping of granophyre. The intrusion, studied by A. B. Ford and W. W. Boyd, Jr., underlies all the Dufek Massif and adjacent Forrestal Range, and has a probable total minimum thickness of about 4,000 m, but neither basal nor upper contacts are exposed. The gabbros occupy a single broad syncline adjacent to more intensely deformed sedimentary rocks, the youngest of which are of Permian age. Investigations of the plagioclases show that cryptic layering is well developed. The anorthite content of plagioclase decreases upward from An_{85} to An_{50}. The plagioclase is of an intermediate structural state and has little change in ordering throughout the vertical extent of the intrusion. A gradual upward increase in interstitial quartz and alkali feldspars, culminating with the crystallization of at least 300 m of granophyre, is accompanied by generally increasing amounts of iron oxides, chiefly magnetite.

Major layers, commonly several meters or more thick, formed by successive lateral spreading, perhaps convectively, of crystal-bearing magma over great distances across the gradually consolidating and rising floor of the intrusion. Some individual layers are traceable for nearly 40 km. The lateral currents scoured the floor at various levels, and the resulting channels were filled with tongues of trough-layered pyroxenite, gabbro, and anorthosite. Iron oxides commonly were concentrated near the base of anorthositic layers, particularly in the higher parts of the intrusion in the Forrestal Range.

Direction and intensity of remanent magnetization and magnetic susceptibility on representative oriented specimens from 45 sites in the Dufek Massif and 17 sites in the Forrestal Range have been measured by M. E. Beck, Jr. Preliminary results of these measurements are:

1. The gabbros of the Dufek Massif are magnetically stable. Their directions of magnetization imply a paleomagnetic pole located near long 164° W., lat 48° S., which is significantly different from other published paleomagnetic poles for Antarctica. The Forrestal Range gabbros, on the other hand, show highly scattered directions of magnetization and are probably much less stable.

2. Both areas contain zones of opposite magnetic polarity. This could mean that the earth's magnetic field reversed its polarity one or more times while the gabbros were cooling through the temperature range in which they acquired their magnetization. Alternatively, this zonation could be the result of mineralogical peculiarities giving rise to a process of self-reversal.

3. Sharp magnetic contrasts exist within the gabbros of both the Forrestal Range and the Dufek Massif and probably can be correlated with differences in lithology developed by magnetic differentiation. Strongly magnetized specimens within the Dufek Mas-

sif have high ratios of remanent to induced magnetization. This, coupled with the existence of magnetic reversals, indicates that strong magnetic anomalies might be produced by magnetic contrasts occurring wholly within the gabbro body itself. The gabbros of the Forrestal Range have high total magnetizations, moderate ratios of remanent to induced magnetization, and (probably) low values of magnetic stability. These characteristics are consistent with an origin by magmatic differentiation in the upper portion of a floored magma chamber.

Deep-seated fault between East and West Antarctica

Simple Bouguer anomalies, computed for 396 gravity stations on bedrock and at seismic-reflection stations on ice, range from +60 mgal on the West Antarctica side of the Pensacola Mountains to −80 mgal on the East Antarctica side (J. C. Behrendt and others, r0639). A steep linear gradient of about 2 mgal/km across the mountains trends northeastwardly along the length of the Pensacola Mountains and is interpreted as an increase in crustal thickness from West to East Antarctica along the Transantarctic Mountains. A model with a 10-km vertical step at the crust-mantle boundary and an assumed crustal thickness of 30 km in West Antarctica fits the gravity data. This step may be the expression of a fault extending through the crust into the mantle.

Frontal faults along the northwestern edge of the Dufek Massif may be a surface expression of the deep-seated fault or fault system. Large aeromagnetic anomalies caused by the gabbroic body underlying the Dufek Massif are not laterally displaced across these surface-expressed faults. This implies that strike-slip movement has not occurred and suggests further that the deep-seated fault system may not have had a strike-slip component, at least since the time of emplacement of the gabbro (Permian or later).

Late Paleozoic continental glaciation

The Gale Mudstone, which occurs over 9,000 square kilometers in the central and northern Pensacola Mountains, is interpreted as an upper Paleozoic tillite by D. L. Schmidt and W. H. Nelson in collaboration with L. A. Frakes (University of California). The formation consists chiefly of dark-gray nonstratified diamictite; less than 5 percent of the unit consists of thin beds of black siltstone and distorted and disrupted layers of tan sandstone and conglomerate.

The Gale Mudstone disconformably overlies the Dover Sandstone of Devonian(?) age and is at least 315 m thick but is probably much thicker. A glossopterid-bearing siltstone-sandstone unit of Permian age is stratigraphically above the Gale.

Grooves on the top of the Dover Sandstone are oriented northward; striae on several boulder pavements within the tillite have similar orientation. Parts of 5 depositional cycles have been recognized in the lower 300 m of the tillite. These cycles represent major changes of glacial regime. Deposition occurred in a subsiding basin that was subjected to later folding, probably during the Mesozoic.

The Gale Mudstone is correlated with tillitic units that occur along the Transantarctic Mountains as far as the Darwin Mountains, about 1,750 km to the west, and with tillite in the Ellsworth Mountains, about 900 km to the northwest. Elsewhere in the Transantarctic Mountains the widespread hiatus between Devonian and Permian sedimentation probably includes the glacial event. Continental glaciation is implied.

Fossiliferous Cambrian limestones

A. R. Palmer has identified an assemblage of Middle Cambrian trilobites of Asiatic aspect from morainal debris near Mount Spann, about 120 km northeast of the Pensacola Mountains. The bedrock source is covered by ice and snow but is likely nearby. The assemblage differs from that of the Middle Cambrian Nelson Limestone of the central Pensacola Mountains and represents either a different limestone unit or a different facies of the Nelson Limestone. The thick, archaeocyathid-bearing limestone of Mount Ferrara, 50 km south of Mount Spann, is a still-different, older limestone unit, probably of Early Cambrian age.

Four different trilobite assemblages of Asiatic aspect and of generally Middle Cambrian age have so far been identified from the central Transantarctic and the Ellsworth Mountains, in addition to the archaeocyathid assemblage of Early Cambrian age that is so widespread in the Transantarctic Mountains from Victoria Land to Coats Land.

Paleobotany of Ellsworth and Transantarctic Mountains

Plant fossils and stratigraphic relations of upper Paleozoic continental deposits in the northern Ellsworth Mountains correspond with those studied in previous seasons in the Forrestal Range (Pensacola Mountains) and the Ohio Range (Horlick Mountains), according to J. M. Schopf. The Ohio Range in the Transantarctic Mountains is 1,000 km from the Ellsworth Mountains. Lithologic facies of deposits below the coal measures of the Ellsworth Mountains compare closely with those of the Ohio Range, although the Ellsworth section is much thicker. The underlying diamictite of the Ellsworth section is much thicker than the corresponding tillite in the Transantarctic areas, but the source and environment of deposition may be slightly different.

Plant collections were obtained by Schopf from a thin 8 to 10 inch bed in the Ohio Range that contains the only known Paleozoic conchostracan fossils from the Antarctic. The conchostracans ("brine shrimps") complement ecological information already obtained from spores, pollen, abundant leaves, and fructification structures. At McMurdo, Schopf also examined fossil-plant collections from localities in Victoria Land for other geologists. These collections, submitted for further study, apparently contain new plant types that are rare or have not been reported from Antarctica.

Glaciation in Antarctica more than 2.7 million years ago

Basalt from several cinder cones in Taylor Valley, Victoria Land, has a K-Ar age of 2.7 m.y. according to R. L. Armstrong and others.[57] The repeatedly glaciated valley, now mostly free of ice, is a composite of a broad outer U-shaped glacial valley and a narrow inner one. The basalt eruptions are younger than the main glacial sculpting of the outer valley, and their age, if correct, dates the major glacial erosion as older than 2.7 m.y. This conclusion is in accord with recent findings of Antarctic glacial maximums between 2 and 3 m.y. ago by study of paleomagnetic-reversal stratigraphy of deep-sea cores around the continent.

Gravity increase at South Pole

Measurements made between December 1957 and January 1966 (J. C. Behrendt, r1083) of the gravity difference between the McMurdo Sound pendulum station, which is on bedrock, and the South Pole station, which is on the Antarctic ice sheet, show a gravity increase at the South Pole of 0.11 mgal per year. The most likely hypothesis for the increase is that it was caused by ice flowing downslope across a gravity gradient and by the sinking of the South Pole station as a result of accumulation of ice. An alternate hypothesis that the gravity increase was caused by a decrease in ice thickness, of about 40 cm per year, is theoretically possible but is not supported by direct evidence.

Map compilation of magnetic data

Absolute total-magnetic-intensity data collected in the area south of lat 55° S. in Antarctica by expeditions of Australia, England, Japan, New Zealand, U.S.A., and U.S.S.R. have been used by J. C. Behrendt to compile a residual total-magnetic-intensity map. Weighted means of residuals of observed data compared with the 1965 epoch map (U.S. Naval Oceanographic Office), corrected for secular variation, were computed for 2-degree squares. Residual anomalies exceeding $+400\ \gamma$ and $-600\ \gamma$ extend over large areas. Generally, West Antarctica appears to have a more positive residual anomaly than East Antarctica. There is a transition zone from positive to negative which is roughly coincident with the Transantarctic Mountains. Other geophysical evidence indicates that these mountains may be related to a structural discontinuity in the crust.

Data for all the available magnetic traverses south of lat 55° S. were used to construct a map showing the areal distribution of narrow-width (<50 km) magnetic anomalies. Numerous anomalies are associated with outcrops of rocks known to have high magnetic properties (for example, the McMurdo volcanic rocks) and extend beneath the ice sheet. Other areas of many anomalies occur beneath the ice or sea where there is no geologic information and thus provide a means of inferring the subglacial or submarine geology.

[57] R. L. Armstrong, Warren Hamilton, G. H. Denton, in press, Glaciation in Taylor Valley, Antarctica, more than 2.7 million years ago: Science.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

International geologic and hydrologic activities of the U.S. Geological Survey during fiscal year 1967 include an intensified program of technical assistance to developing countries through the U.S. Department of State, the United Nations, and other organizations; continued scientific collaboration through international earth-science associations and programs; and joint research with scientific agencies in other nations on problems of mutual concern.

Under the Geological Survey's program of technical assistance, 133 specialists were assigned to 31 countries at the request of other governments during the fiscal year, and academic or practical study was conducted or arranged in the United States for 92 earth scientists and engineers from abroad. Table 1 summarizes the type of assistance given each country during the year. In more than a quarter of a century of technical assistance, the Geological Survey has sent 782 members of its staff on investigations and training assignments to 73 countries and has provided training in the United States for 917 scientists from 77 countries.

In its international assistance program, the U.S. Geological Survey (1) conducts cooperative projects with counterpart agencies under government-to-government agreements through the U.S. Department of State, most of which are sponsored by the U.S. Agency for International Development (USAID), and (2) provides scientists for special assignments with the United Nations and other international organizations. Most of the Survey's cooperative projects abroad involve assistance in strengthening earth-science institutions or cadres of scientists, together with geological mapping and appraisal of host-country resources or investigations of geological phenomena that affect social and economic development. During fiscal year 1967, the Survey, in cooperation with counterpart agencies, conducted joint broad-scale assistance projects involving institution building and geologic or hydrologic surveys in 14 countries: Afghanistan, Bolivia, Brazil, Colombia, Costa Rica, Guyana, Korea, Liberia, Nepal, Nigeria, Pakistan, Saudi Arabia, Turkey, and the United Arab Republic. Special studies of geologic or hydrologic phenomena, or short-range advisory assistance projects on geologic and hydrologic problems, were undertaken jointly with counterparts in 23 countries: Aden, Argentina, Australia, Barbados, Brazil, Chile, Costa Rica, Ecuador, Ethiopia, India, Jamaica, Kenya, Korea, Morocco, Nepal, Nigeria, Pakistan, Philippines, Saudi Arabia, Spain, Thailand, Turkey, and Vietnam. With the exception of Saudi Arabia and Turkey, the long-range programs and special studies were undertaken under the auspices of the Agency for International Development, U.S. Department of State. In addition, the Geological Survey began a regional analysis of fertilizer-mineral-resources potential in Latin America under the auspices of the Inter-American Development Bank.

More than 892 technical and administrative documents involving Geological Survey authors have been issued as a result of the Survey's technical assistance program. During fiscal year 1967, 38 reports were published and 96 technical and administrative documents were prepared (table 2).

International scientific collaboration by the Geological Survey included participation in the activities of the International Union of Geological Sciences; International Union of Geodesy and Geophysics; International Atomic Energy Agency; Food and Agricultural Organization; World Meteorological Organization; United Nations Educational, Scientific, and Cultural Organization; International Hydrological Decade; and other international agency and association programs. Geological Survey scientists also continued joint volcanological studies under the Japan–United States Scientific Exchange Agreement; compilation of continental geologic, tectonic, and metallogenic maps in cooperation with other scientists under the International Geological Commission for the Geological Map of the World; and cooperative research in other countries on geological phenomena of importance in the United States, such as studies of earthquake phenomena in Turkey and Chile, hydrogeochemical features of limestone terrane in Mexico and the West Indies, and glaciological phenomena of permanent snowfields in the Andean region of South America. In addition, Survey specialists participated in a number of working groups and conferences under the United Nations Economic Committee for Asia and the Far East, Central Treaty Organization, Pan American Health Organization, Organization for Economic Cooperation and Development, and other regional agencies.

TABLE 1.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1967*

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	C	1	Photogeology and petrography.
	1	Chemist	D	1	Geochemistry.
	1	Hydraulic engineer	D	1	Mineral exploration techniques.
Barbados	1	Hydraulic engineer	D		
Bolivia	4	Geologist	A, C	1	Engineering geology.
				1	Geochemistry.
				1	Economic geology.
				1	Paleontology.
				1	Laboratory techniques.
Brazil	9	Geologist	A, B, D	1	Natural resources surveys (minerals).
	1	Administrative officer	----------	1	Hydrogeology.
	1	Cartographer	----------	1	Economic geology.
	4	Hydraulic engineer	A, B, D	1	Minerals exploration.
	1	Hydrologist	D	1	Water-resources development.
	2	Hydrogeologist	A, B	1	Ground-water exploration techniques.
				1	Geohydrology.
				4	Ground water exploration.
				1	Hydrology.
Chile	1	Hydrogeologist	D		
Colombia	1	Hydrogeologist	D	3	Economic geology.
	11	Geologist	A, B, C, D	2	Cartography, photogrammetry.
				1	Photogeology.
				1	Micropaleontology.
				1	Mining geology.
Costa Rica	2	Geologist	C		
	2	Geophysicist	D		
Ecuador	1	Geologist	D		
Guyana	5	Geologist	C	2	Spectrographic techniques.
				2	Water resources.
Jamaica	1	Hydrogeologist	D		
Mexico	1	Geologist	D		
Venezuela		----------	----------	1	Photogeology.
				1	Stream-gaging techniques.
Africa					
Ethiopia	1	Geologist	D		
Ghana	----	----------	----------	1	Drilling and engineering (water resources).
Liberia	6	Geologist	A	2	Geology.
	1	Administrative officer	----------	1	Geophysics.
	1	Secretary	----------	1	Geologic administration.
	1	Cartographer	A		
	1	Cartographic technician	A		
Kenya	1	Hydrogeologist	D		
Morocco	1	Hydrogeologist	D	1	Geochemistry.
Nigeria	3	Hydraulic engineer	C		
	1	Chemist	B		
	2	Hydrogeologist	A, C		
Republic of Guinea	----	----------	----------	1	Geophysics.
Swaziland	----	----------	----------	1	Geology, geochemistry.
United Arab Republic	1	Hydraulic engineer	A		
	1	Hydrogeologist	B		
	1	Hydrologist	D		
Uganda	----	----------	----------	1	Photogeology.

See footnote at end of table.

TABLE 1.—*Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1967*—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					
Aden	1	Hydrogeologist	D		
Afghanistan	4	Hydrologist	A, C	1	Photogeology.
	1	Hydrogeologist	D	1	Surface and ground-water studies.
				1	Cartography.
Cyprus	----	----	----	1	Ground-water development.
Egypt	----	----	----	2	Ground-water investigations.
India	2	Hydrogeologist	D	1	Hydrogeology, photogeology.
	1	Photographer	D	1	Mineral deposits.
Israel	1	Hydrologist	D	1	Seismic geophysics.
Nepal	1	Hydraulic engineer	A	1	Hydrology.
	1	Geologist	D	6	Hydrologic investigations.
Pakistan	5	Hydrologist	A, B, D	1	Ground-water hydrology.
	2	Hydrogeologist	D	1	Ground-water survey and water quality analysis.
				2	Geohydrology.
				1	Mineral exploration, geophysics.
				1	Chemistry, geochemistry.
				3	Hydrology.
				1	Water quality analysis.
				1	Hydrology, isotope techniques.
Saudi Arabia	18	Geologist	A, B, C	1	Isotope geology.
	1	Administrative officer			
	1	Secretary			
	2	Geophysicist	B		
	1	Geochronologist	B		
	3	Driller			
	1	Photogrammetric engineer	B		
	1	Topographic engineer	B		
	1	Geodesist	B		
Turkey	1	Hydrologist	D	1	Ground-water resources.
	1	Geologist	D	1	Technical report writing.
				2	Photogeology.
				1	Radioisotopes ground water.
Far East					
Australia	1	Hydrogeologist	D	1	Water-resources investigations.
Japan	----	----	----	1	Petrology, isotope geology.
				1	Trace elements.
Korea	1	Hydrologist	B	1	Exploration geophysics.
				1	Hydrology.
				1	Geochemistry.
				1	Photogeology.
Philippines	1	Hydrogeologist	D	2	Ground-water geology.
				1	Mineral economics.
Thailand	2	Hydrologist	D	1	Hydrology.
	1	Geologist	D		
Vietnam	3	Hydrologist	D	1	Ground-water development.
Other					
Iceland	----	----	----	2	Geohydrology.
Germany	----	----	----	1	Seismology.
Netherlands	----	----	----	1	Chemical analysis.
Spain	1	Hydrogeologist	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 phenomona or resources; D, short-range advisory help on geologic or hydrologic problems and resources.

TABLE 2.—*Technical and administrative documents issued in fiscal year 1967 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 the U.S. Geological Survey and counterpart agencies	Reports published by outside technical journals	Reports published or released by the U.S. Geological Survey
Afghanistan		1		
Brazil	13	3	3	4
Bolivia	1			
Chile	3	1		
Colombia	2	3	2	1
Costa Rica	8	2		
Dahomey	1			
Ecuador	1			
Guyana	2	1		1
India	1	2		
Indonesia				1
Iran	1			
Korea	1			
Liberia	2	5		
Libya		3	1	
Mexico		1		1
Nepal	1	1	1	
Nigeria		3		1
Pakistan	13	18	1	1
Philippines	1			
Saudi Arabia	41	12	1	13
Sudan		1		
South America		1		1
Thailand	3	5	3	
Tunisia				2
Turkey	1			
Total	96	63	12	26

Significant results of Geological Survey investigations abroad are summarized in the following paragraphs. Additional details concerning some of the Survey's investigations in other countries may be found in other sections of this chapter. International topographic work, including activities in Antarctica, are discussed in a separate section.

SUMMARY BY COUNTRIES

BOLIVIA

District mineral studies

Detailed appraisal of mineral resources has recently been started in three of Bolivia's mineral districts, under the guidance of U.S. Geological Survey (USGS) geologists working with the Geological Survey of Bolivia (GeoBol). In the Sorata district the mineralization is related to the Sorata and Yani batholiths. Sam Rosenblum has found that the batholiths have domed(?) Paleozoic slates and quartzites, baking the slates to spotted cordierite phyllites in the contact zones. The batholiths range in composition from quartz monzonite to muscovite granodiorite; associated with and genetically related to them are veins containing tin, tungsten, copper, lead, silver, gold, bismuth, and molybdenum. Most of the present mines are clustered around the Sorata batholith, which has been shown by K-Ar dating to be about 200 m.y. old. The age of the Yani batholith is unknown and, because of difficult access, its relationship to the Sorata batholith has not yet been determined.

Cretaceous strata in the Sorata district contain at least 2.5 million tons of gypsum suitable for the manufacture of plaster products.

H. S. Jacobson (USGS) and counterparts from GeoBol have found that mineral deposits in the San Cristobal district are of four distinct types: (1) sulfide veins containing lead, zinc, and silver minerals, associated with dacite porphyry intrusive stocks, (2) oxide veins containing iron and silver, associated with andesite porphyry intrusive rocks, (3) sulfides partly replacing intrusive breccia with the resulting concentration of silver, lead, and zinc, and (4) altered dacite porphyry intrusive and adjacent altered sedimentary rocks containing disseminated lead-silver-zinc minerals. Disseminated silver minerals may possibly warrant the development of open-pit silver mines.

The rocks of this district are all Tertiary and Quaternary. The oldest are the agglomerate, conglomerate, sandstone, and tuff of the flat-lying Quehua Formation, which are overlain by the red beds of the Potoco Formation. Both formations were intruded by dacite porphyry and andesite porphyry stocks, and both are overlain by Recent dacite porphyry lava flows. The intrusive and sedimentary rocks near the intrusive contacts are hydrothermally altered.

Prospects are very favorable for the opening of a major tin mine in the Quimsa Cruz mineral district as a result of work reported there by Walter Thormann (USAID) as part of the mineral-investigations program with GeoBol. In the Barraskota area an estimated reserve of ore containing approximately 1,000 tons of tin metal is indicated. One vein 30 cm thick assayed 10 percent tin, and the mineralized zone, about 1.5 m thick, averages about 3 percent tin. Three drill holes nearby have cut veins about 1 m thick containing 2.8 percent tin and 22 m of stockwork containing as much as 3 percent tin. The drilling and surface sampling indicate that the concentration and extent of tin mineralization may be suitable for open-pit mining.

Regional geologic mapping

A continuation of the mapping started by J. F. Seitz in the Quimsa Cruz range has shown that the Cordillera Real is bounded by two fault zones. Ten kilometers northeast of the Quimsa Cruz batholith the Inquisivi fault separates Ordovician and Silurian rocks of similar types and dips steeply southwest; about 100 km to the southwest the Calamarca fault parallels the Inquisivi fault, dips vertically, and is marked by a zone of dacite stocks over a distance of 70 km. The horst block between these two faults is broken by many minor parallel faults. The Quimsa Cruz batholith has been shown to be about 26 m.y. old by K-Ar dating in U.S. Geological Survey laboratories.

Regional geologic mapping of Bolivia's Altiplano (high plateau) under the direction of Stanislav Kriz (USAID) and supervised by USGS personnel has been the basis for a planned $30 million exploration program by Bolivian Gulf Oil Co. in cooperation with Yacimientos Petroliferos Fiscales Bolivianos, the Bolivian government oil company. Two huge Cretaceous basins were mapped that have favorable petroleum source and reservoir rocks. Pre-Cretaceous gypsum has moved upward through Cretaceous and Tertiary layers along a number of anticlinal axes.

Colluma Crater investigation

Colluma Crater, about 120 km west-southwest of Oruro, Bolivia, is an oval-shaped domal structure partly buried by Quaternary gravels of the western desertlike Altiplano. The structure is 6.7 km by 6.0 km overall and consists of generally outward dipping, poorly consolidated gravel, sand, silt, and lenses of white calcareous clay. Forming the walls of the crater are two cuesta-form rims in which strata dip as much as 30°. The rims of the crater are a little over 3,900 m in altitude, and the lowest altitude inside the crater is 3,840 m, slightly higher than the surrounding plain. Drainage within the inner rim is entirely inward to a playa-type pond; elsewhere the drainage is outward.

In 1965 general information about the crater was obtained during a regional mapping program. Because it may have been of impact origin similar to the Campo del Cielo Craters of northern Argentina, Sam Rosenblum and Reed Anderson led a small party in May 1966 which briefly investigated the crater for evidence of origin. Magnetometer and electromagnetic surveys across the floor showed no anomalies. Soil samples from the crater showed no unusual nickel or iron content and were virtually the same as the soil samples taken 12 km east of the structure. Strata cropping out within the crater and along the rims are not everywhere conformable with the trends of the crests. Interior outcrops are obviously being buried by in-filling from the inner rim. The profiles of both rims are somewhat rounded by erosion.

Only impact of a meteorite or collapse of a dome could produce a crater of the general depth and size of the Colluma Crater. If it had been formed by a meteorite, evidence of the event should be preserved in chaotic structures in the rims, glass fragments, and impregnations of nickel and iron in the soils. By projecting the N. 60° E. line of the Campo del Cielo meteorite swarm from a point 22° west of the Campo del Cielo path, as suggested by Cassidy and others,[58] to intersect the Chilean occurrence of hexahedrites, it was found that Colluma Crater is 65 km north of the second pass of the swarm around the earth. A path starting 23½° west of Campo del Cielo would intersect Colluma Crater, but not the Chilean meteorite sites.

On the basis of the above data and because of the lack of recognizable meteorite fragments, impact glass, or volcanic layers, both impact and volcanic origins were rejected. Because the rims are continuous and undisturbed, a "gas blister" hypothesis was similarly rejected. Normal doming seems improbable, for the inner rim is not breached by stream erosion, as it would have been during formation of an eroded dome.

A mechanism that satisfies the observations would be doming of the soft sediments, perhaps in early Pleistocene time, by a volcanic plug that did not quite reach the surface; on retraction of the intrusive, enough empty space might have formed between the plug and the sediments to allow the center of the dome to collapse as much as 200 m. Subsequent erosion and in-filling could have produced the structure as it appears at the present time. Thus, owing to the lack of other evidence, Colluma Crater is considered to be a collapsed dome. Confirmation of this may be supplied by further geophysical evidence.

BRAZIL

Natural-resources survey

Mineralogical studies have been completed in the laboratory of the Brazilian National Department of Mineral Production (DNPM) on samples from a phosphate deposit recently discovered by geologists of the Brazilian National Nuclear Energy Commission in the Jatobá basin in the south-central part of the State of Pernambuco in northeast Brazil. The laboratory studies

[58] W. A. Cassidy, 1965, Meteorites and craters of Campo del Cielo, Argentina: Science, v. 149, no. 3688, p. 1055–1064.

by J. J. Matzko (USGS), and Malvina Pomerancblum (DNPM) have identified the phosphatic mineral as a carbonate-fluorapatite containing trace amounts of crandallite and autunite. The highest phosphate content, 30 to 35 percent P_2O_5, is in reddish ferruginous argillite and argillaceous lenses in two units of the Inaja Formation of Devonian age. The lenses, from 2 cm to 1.5 m thick, vary widely in phosphate content, and are themselves not of economic importance, but they provide the basis for further investigations of similar rocks within the area and to the north and northwest of the Jatobá basin.

R. H. Nagell (USGS) and counterparts from DNPM have completed detailed geological mapping and study of structural control of the ores at the Boquira lead mine in the State of Bahia. The ore minerals, mostly galena with some sphalerite, are in steeply dipping veins as much as 4 m wide. Most of the ore mineralization seems to be confined to hard competent amphibolite. Cross faults cut off the ore in some veins, but others terminate without obvious control by faults, change in wallrock, or change in attitude. Chlorite is common in the wallrock and is the dominant vein mineral, where it forms gouge along fault surfaces. The rocks are schistose with parallel alinement of the long axes of mineral grains. Replacement of other minerals by magnetite and dolomite is indicated by textural relationships. Drag folds and the relation of fracture cleavage to bedding indicate that the rock containing the lead deposits forms the overturned west limb of a northerly plunging anticline. The center of the anticline is obliterated by granitic intrusions.

Landslide and engineering-geology investigations

As a result of the disastrous floods and landslides that occurred in Rio de Janeiro and vicinity in 1966, F. O. Jones (USGS) spent the rainy season of 1967 in Brazil investigating landslide and slope stability problems. Again in 1967 unusually heavy rains struck the Rio area, resulting in extensive damage and loss of life. Some 40 to 50 landslides in the steep canyons above the Nilo Pecanha underground powerplant tunnel turned to mudflows in the valley bottom and buried the main generating units supplying power to Rio. Slides and mudflows in the Lajes River canyon filled the tailrace channel of the new Fontes plant and temporarily interrupted the inlet of a water supply line to the city. The São Paulo–Rio de Janeiro highway was cut by slides and mudflows in numerous places. The floods from many tributaries converged in the Rio da Floresta Valley at the toe of the mountains, forming a mudflow which engulfed virtually an entire village and a highway construction camp.

The stabilization of some slopes that have already failed in Rio is considered to be impractical, but preliminary tests indicate that subsurface drainage and stiffening of many of the soils can be induced by applying lime to the surface. Of 190 soil samples taken from different geographic areas and diverse parent rocks, 87 percent have reacted positively, that is, they are probably amenable to treatment with lime. Continued soil research has been recommended, as well as research on stability of rock in various degrees of alteration. Terrain analysis has also been recommended to determine possible new routes for sections of the São Paulo–Rio de Janeiro highway.

Poor-quality ground water can be made potable

According to L. G. Chada Filho and Mario Dias Pessoa, of the Superintendency for the Development of the Northeast (SUDENE), and W. C. Sinclair (USGS), the Upper Capibaribe Basin in the State of Pernambuco contains water principally in thin alluvial fill which occurs in narrow bands along the rivers and in weathered and fractured granite, gneiss and schist, and other crystalline rocks. By rough estimate 4,700 million cubic meters of water was precipitated in 1964 as rain on the Upper Capibaribe Basin, and of this, 57 percent left the basin as overland runoff and 43 percent went into underground storage, or was evaporated and transpired. Poor-quality water both on the surface and underground is common in the basin. Some ground water could be made potable by dilution with rainwater which could be collected during the rainy seasons and stored.

Large ground-water sources in the Açu Valley

H. G. Rodis (USGS) and J. M. deCastro Araújo, of the Hydrogeology Division, Superintendency for the Development of the Northeast (SUDENE), report that water in the alluvial fill of the Açu Valley in the State of Rio Grande do Norte was being withdrawn at the rate of 2,250 thousand cu m annually in 1964 or about 90 cu m from each hectare meter of saturated alluvium. This draft is being taken from some 800 shallow dug and driven wells for irrigation, domestic, and stock use. The Açu Sandstone and Jandaíra Limestone, both of Cretaceous age, are potentially important, but virtually untapped aquifers that underlie the alluvial fill. About 22 million cu m of water would be required to irrigate the total bottom land (25,000 hectares) in the valley, and this withdrawal would be equivalent to about a fourth to a half of the estimated recharge from precipitation alone.

COLOMBIA

Regional geologic mapping

Two years of systematic geologic reconnaissance mapping by about 40 geologists of the Colombia Mineral Inventory, with guidance and technical assistance from 6 USGS geologists, has provided considerable new data on the pre-Cretaceous history of Colombia. Because fossils are very scarce in the marine rocks and because most of the rocks are metamorphic or igneous, a systematic attempt is being made to determine rock ages and to define major events by radiometric dating.

Precambrian rocks, possibly representing a westerly projection of the Guyana shield, crop out in the central Andes as local windows beneath younger rocks in the Cristalinas area (Antioquia). These rocks are overlain by Ordovician phyllites. Other rocks identified in four widely separated areas of the northern Andes are carboniferous and Permian strata: thick sequences of red beds of the La Quinta and Girón Formations, generally considered to be Jurassic-Triassic; Cretaceous marine rocks; and continental Tertiary deposits. The La Quinta and Girón Formations are intruded by grantic plutons that are tentatively dated at 170 m.y., and in the Santa Marta and Antioquia areas, Lower Cretaceous sedimentary rocks and all older rocks are intruded by batholiths dated at 70 m.y. (Late Cretaceous). In the extreme northwestern part of the Santa Marta mountains, the age of a granitic pluton that intrudes a thick sequence of green schists was determined to be 50 m.y.

Phosphate investigations

Phosphorite of potential economic interest has been identified in Colombia by J. B. Cathcart (USGS) and Francisco Zambrano O. and Pedro E. Mojica G., Colombia Mineral Inventory. The deposits were found in both the geosynclinal and the platform facies in the Upper Cretaceous Guadalupe and La Luna Formations. They are spread through a large area of the Cordillera Oriental, extending from Huila in the south to Norte de Santander in the north, a distance of more than 600 km. Some of the deposits are believed to have potential for economic development as chemical fertilizer; others may be suitable only for local use for direct application to the soil. These studies have shown the importance of prospecting for phosphate in miogeosynclinal areas where deposition of clastic sediments was at a minimum and where the rocks are characterized by chert, black shale, and carbonate rocks.

Salt deposits

D. H. McLaughlin, Jr., has completed studies of evaporite deposits in Colombia and has concluded that the salt deposits north of Bogota are stratigraphically in situ and were deposited in relatively small, stagnant marine basins located near the outer, more basinward, parts of the Late Cretaceous miogeosyncline.

The Zipaquira and Nemocon deposits, which are associated with the axial portions of local structurally deformed anticlines, are intimately interstratified with black argillaceous material, giving the entire evaporite sequence a characteristically banded aspect. Irregular fragments of black, calcareous claystone, ranging from several millimeters to more than a meter in major dimension, are scattered randomly throughout the deposits. Also, numerous large, mappable black claystone units are concordantly interbedded with the salt sequence of the two above named deposits.

Deformation within the Zipaquira and Nemocon deposits, which are being mined, can be accounted for by compressive stresses that developed the regional structure in that part of the eastern Andes; the deformation is not considered to have resulted from diapiric intrusion. Although salt flowage has taken place at both deposits, the general structural picture is not comparable to that of the salt domes on the Gulf coast of the United States.

Talc deposits

Exploration of talc deposits north of Yarumal and in the vicinity of Bufalo in the central Andes is very encouraging. Diamond core drilling indicates that between 10 and 20 million tons may be present. However, the potential market would be greatly expanded if ore-dressing techniques could be found to remove iron-bearing minerals; samples have been submitted to the U.S. Bureau of Mines for testing.

Laterite

The Ure laterite deposits in the central Andes are being explored primarily because of interest in the nickel content. The exploration, which is by test pitting, has disclosed an enriched zone of 3 to 4 m thickness where a nickel content of 1 to 2 percent has been found. However, the area of these laterite bodies does not appear to exceed a few square kilometers.

COSTA RICA

Volcanologic investigations

Since 1963, as a result of the 1963–65 eruptions of Irazú Volcano, volcanologic studies have been made by the U.S. Geological Survey in cooperation with the Costa Rica Office of Civil Defense and the Geological Survey of Costa Rica. R. D. Krushensky and F. D. Spencer (USGS) have also completed studies of the effects of recent eruptions by the volcano Rincon de la Vieja.

Recent eruptions of ash and vapor from Rincon de la Vieja have directly affected only a small area high on the southwest slope of the volcano. The eruptions were chiefly water vapor, small quantities of sulfur dioxide, and accessory ash; that is, ash derived from the old, previously solidified and weathered lava that forms the throat of the volcano. Sulfur dioxide dissolves easily in water droplets in clouds and rain, and it may be oxidized to sulfuric acid. Apparently very locally, concentrations of this acid gas were sufficiently great to irritate the eyes and exposed skin of persons in the vicinity. Although the eruptions have so far affected only a small area having little economic importance, the waters of the Colorado, Tempisque, and Blanco Rivers presently show a gray discoloration and a pH of 3.2, and are locally unusable for domestic or agricultural purposes.

Engineering-geology studies in Reventado River watershed

During the past 4 years heavy ash fall from Irazú Volcano has killed vegetation and greatly increased runoff, resulting in floods and mudflows along the Reventado River and in the city of Cartago. The sequence of strata on the flanks of the volcano indicates an outpouring of andesitic lava and ash throughout its history. Most of the ash is now in lahar beds, although some ash beds are also present. All the lahar and ash beds are unconsolidated and relatively unstable, and they furnish the bulk of the debris to the mudflows. Locally, erosion in the lahar beds has widened stream channels by as much as 200 percent. Active and inactive landslides cover about 50 percent of the Reventado River watershed. Two of the four major active slides have moved as much as 50 m horizontally and 30 m vertically since 1963. The chief causes of landsliding are removal of the toes of slopes and infiltration of surface and ground water. Knowledge of the almost unlimited supply of debris available for stream transport or inclusion in mudflows is essential in any planning for remedial control structures in the city of Cartago or higher in the watershed area.

In addition to studies of landslide and mudflow problems in Costa Rica, engineering-geology studies have been made of two alternate sites for a proposed debris storage dam on the Reventado River. Both of the proposed sites are underlain by lavas and lahars. R. D. Krushensky has concluded that the upstream site is better suited for the construction of the dam.

Investigation of Cordillera Central

The Cordillera Central of Costa Rica consists of irregularly interbedded andesitic lava flows, lahars, ash-flow tuffs and air-fall tuffs. The Cordillera is limited on its southern margin by an east-trending graben that cuts across the southeast-trending structural grain of the country. R. D. Krushensky has mapped a stratigraphic sequence that includes most of the material of Turrialba and Irazú Volcanos in the eastern third of the Cordillera. Rocks of this group lie unconformably on an unnamed welded tuff. This tuff is the first unit known that can be used to correlate stratigraphically the rocks of the Cordillera Central with the folded lower Miocene rocks in the Talamanca Range to the south. A radiometric minimum age for the end of the Talamancan (Andean) orogeny is not yet available, but a maximum age of early Miocene is shown by the folding of fossiliferous lower Miocene rocks.

GUYANA

Mineral appraisal of Peter's mine area

A. E. Weissenborn (USGS) studied the Peter's mine area in Guyana, including the abandoned mine itself, with C. N. Barron, Deputy Director of the Guyana Geological Survey Department (GGS) and found that the mine area still holds attractive possibilities if problems of transportation can be solved. The only present means of access is by boat from Issano on the Mazaruni River, but it may be feasible to construct an airstrip at the mine to accomodate light planes.

The gold deposits are in Precambrian psammitic and pelitic schist which is part of the Cuyuni Formation of the Mazaruni Group. The mine area is near the western edge of a body of granitic rock. Free gold is present in a system of large quartz veins, but pay streaks are erratic. Some surface samples assayed as much as 7 ounces of gold per ton of rock, although most samples from diamond drill holes put down by the GGS about 2 years ago were disappointingly low. However, correlation of vein structures and additional analyses of drill cores indicate that one block of ground may have a production potential of about 160,000 ounces of gold and that mineralized structures continue to depths of at least 600 feet and extend laterally several hundred feet. Past production has come from an area only 200 by 300 feet in extent and mainly from depths of less than 200 feet. Thus, further exploration seems justified.

Weissenborn has summarized the findings of the study in a Geological Survey open-file report, (r0851).

Geochemical study of molybdenum deposits

Molybdenum-bearing soils have been known for several years to overlie two granite masses in the Eagle Mountain area of Guyana. A geochemical study was made in March 1966 by W. R. Griffitts and F. N. Ward (USGS) and M. W. Carter and A. O. Edwards, of the Guyana Geological Survey Department, to define the limits of geochemistry as a tool in prospecting for molybdenum, and also to reevaluate the Eagle Mountain deposits.

The study showed that the molybdenum content of soil varies from one soil horizon to a lower one by a factor of at least 4. In most places the B zone of the soil profile commonly has a higher and more consistent molybdenum content than the shallower soil material. The uppermost inch or two of soil is locally exceptionally high in metal content in some places and could cause erratic results if included in samples. The weathered rock (C zone) is rather uniform, and contains as much as 70 ppm Mo. Stream sediments contain molybdenum as detrital particles washed down from the anomalous soil areas and as material precipitated from water seeping into the streams.

The study indicates that soil samples can be used effectively to outline molybdenum deposits, that the boundaries of the anomalous soil areas are sharp, that molybdenum does not move far laterally to give false anomalies in soil over barren rock, and that soil samples should be taken from the B zone, usually at a depth of 12 to 20 inches. Also, ranges of metal content in anomalous soils must exceed a factor of 4 before they can be considered significant, and because of short dispersion trains in stream sediments samples must be taken within 0.5 miles of the deposit to be certain of detecting it.

New minerals found in merumite

For several years Charles Milton and coworkers of the Geological Survey have been studying merumite, a rock found in placers and alluvial gravels in Guyana. It forms black rounded grains usually less than a centimeter but rarely as much as 15 cm in diameter. Analyses vary from specimen to specimen, but the average composition is 80 percent Cr_2O_3, 8 percent Al_2O_3, 1 percent Fe_2O_3, 0.5 percent SiO_2, 0.5 percent V_2O_5, and 8 percent H_2O. The streak is olive green to dark brownish black. Some specimens contain doubly terminated quartz prisms, and contain microscopic pale-green pyrophyllite in vugs.

Merumite has been found to be a complex intergrowth of at least three major components and at least as many minor ones. The major components, which constitute more than 90 percent of the several hundred specimens studied, are green eskolate, Cr_2O_3; a brown orthorhombic mineral (n. sp.), CrOOH, isostructural with geothite; and a reddish-black unnamed mineral (n. sp.), also probably a hydrous chromium oxide. Minor components are two red-brown minerals (n. spp.), CrOOH, and CrOOCu, both rhombohedral; and a violet zinc-chromium spinel (n. sp.) associated in minute crystals with the grimaldiite-mcconnellite. CrOOH is very rarely found alone but is almost always intergrown microscopically with CrOOCu. The two minerals, however, can be differentiated by their X-ray patterns and recognized individually with the electron microprobe; they can also be discerned optically in some photographs of the two-phase platy hexogonal "single crystals." Some specimens of merumite contain gold.

A hydrothermal origin for merumite is suggested by the enclosed doubly terminated quartz crystals and the pryophyllite and gold.

The deposits are now being systematically explored to determine their extent and characteristics and to ascertain, if possible, the source of the merumite.

INDIA

Full potential of ground-water reservoir in India not yet utilized

According to a report by P. H. Jones and Walter Hofmann (r2103), all the water of the Upper Gangetic Plain, both on the surface and underground, is a hydrologic continuum that must be appraised, developed, and managed conjunctively, if India is to get the most benefit from irrigation agriculture in the region and move toward its goal of self-sufficiency in food production. This vast plain of some 64 million acres is underlain by water-bearing alluvial deposits to a depth of 1,500 feet or more. At present there are some 50,000 private or public tubewells in the plain that yield individually from 1 to 1.5 cfs. Although present pumpage of ground water is large indeed, the full potential of the ground-water reservoir has not been realized, and moderately intensive hydrologic investigation is needed to determine this potential.

KOREA

Ground-water reconnaissance of Cheju Do Island

J. T. Callahan reports that Cheju Do, an elliptical island located about 100 km south of the Korean Peninsula, is formed chiefly by a single central volcanic cone of interbedded basalt flows and pyroclastic deposits and rises to 1,950 m above sea level. Superimposed on the central cone are several scores of satellite cinder cones, some of which are more than 200 m high. Ground water moves chiefly through permeable scoriaceous zones in basalt flows that give rise to many springs, some of which flow at rates of more than 10 mgd. Reconnaissance indicates that available ground-water supplies are only slightly developed and that a large potential exists for additional recovery by wells, galleries, and spring development.

LIBERIA

Mineral resources

J. B. Pomerene (USGS) and W. E. Stewart, Liberian Bureau of Natural Resources and Surveys (BNRS), investigated barite deposits in the eastern part of Montserrado County and the southwestern part of Bong County, Liberia. Six deposits were mapped and explored by trenches and pits in an effort to determine their dimensions. Two deposits seem to be large enough to be of commercial value, and a conservative estimate of their reserves is 10,000 metric tons per meter of depth. If the veins extend to a depth equal to their strike length, the district may contain 1–2 million tons of barite. Factual data regarding the subsurface dimensions and attitude of the barite bodies are lacking, however, and diamond drilling, extensive trenching and resistivity surveys have been recommended. Initial semiquantitative analyses indicate that the deposits are probably 99 percent pure $BaSO_4$.

S. A. Stanin (USGS) and Bismarck Cooper (BNRS) are investigating kyanite-bearing gneiss in the Mt. Montro area near Hartford, Grand Bassa County, Liberia. The strongly foilated rocks, which strike northwest and dip 40° – 60° S.W., underlie an area approximately 8 miles long and 1 mile wide. Preliminary investigations have delineated a zone approximately 1 mile long and 150 feet thick containing 7 to 40 percent kyanite and averaging about 20 percent. Preliminary results are encouraging in terms of total quantity of kyanite available, apparent grade of material, and mining-transportation logistics.

Geologic mapping, geochronology, and petrographic studies

Geologic mapping in western Liberia by teams of USGS and BNRS geologists and by mining companies has shown that nearly all the mapped area is underlain by Precambrian crystalline rocks. The rocks are predominantly granitic gneisses, associated quartzites and metapelitic rocks, hornblende amphibolites largely of intrusive origin, metamorphosed ultramafic rocks, and, locally, thick sequences of itabirite with iron-enriched zones. The metamorphic grade of crystalline rocks generally corresponds to the amphibolite facies, but rocks of granulite facies are common, and itabirite and associated rocks in large areas are only slightly metamorphosed. Abundant diabase dikes as much as several hundred feet thick cut the crystalline rocks toward the interior of the country; near the coast, sill-like younger diabase bodies cut sedimentary rocks of possible Tertiary age.

Foliation in the gneiss is commonly related to moderate to intense shearing. The regional trend is dominantly northeast, but many structural complexities are evident. Granitic rocks in which foliation is weak or absent underlie much of the northwestern part of the country, but structural, textural, and compositional features suggest that these rocks may represent partly remobilized zones in the gneiss rather than discrete intrusive plutons. Except for local, small pegmatite bodies, no granitic intrusions have been recognized to date.

Rb-Sr age determinations on granite rocks from Liberia are being made by P. M. Hurley and coworkers at the Massachusetts Institute of Technology geochronology laboratory, with support in Liberia by G. W. Leo (USGS). Preliminary determinations on 26 samples of granitic rocks from nine localities show an approximate age range of 2,400 to 3,400 m.y.; two determinations from a tenth locality gave 685–995 m.y.

Partly concordant, partly crosscutting metamorphosed ultramafic plugs as much as 3 miles long and 1 mile wide have been mapped by G. W. Leo (USGS) and S. P. Srivastava (BNRS) near the Lofa River about 60 miles north of Monrovia. Toward their interiors, the plugs are massive and blocky and consist dominantly of amphiboles, olivine, and subordinate amounts of chlorite and serpentine. Toward contacts with gneiss, the rocks become foliated, olivine is progressively serpentinized, and water content increases. It is tentatively concluded that the ultramafic rocks were intruded prior to or during regional metamorphism, were converted to present mineral assemblages, and were marginally sheared and foliated in response to the regional stress pattern.

NEPAL

Phosphate studies

As a result of the discovery of possible commercial phosphate rock in the foothills of the Himalayas of Uttar Pradesh, India, a brief investigation was made by R. P. Sheldon (USGS) to see if the rocks extend into Nepal. From the field studies, it appears that the phosphate-bearing formation of Uttar Pradesh does not extend into Nepal, and phosphate was not found to be associated with other sedimentary rock sequences thought to be favorable.

In India the phosphate deposits are at the base of the Tal Series of Jurassic-Cretaceous age, a major rock unit overlying the Krol Series. Although some geologists have suggested that in Nepal a unit generally correlative with the combined Krol and Tal Series exists, it is likely that the Nepal unit does not contain the Tal Series correlative at all localities. Inasmuch as there is structural discordance in Nepal between the Krol Series and overlying Eocene rocks, it is possible that the Tal Series may have been cut out by faulting or by erosion locally, and it may crop out in areas not studied.

PAKISTAN

Hazara-Kashmir syntaxis

A new explanation for the sharp hairpin bend in the southern Himalaya has resulted from work done by geologists of the U.S. Geological Survey and the Geological Survey of Pakistan. Called the Hazara-Kashmir syntaxis, this tight northward-projecting loop in the southern Himalayas of Pakistan and Kashmir is thought to be related to the great regional arc that includes the entire 200-mile width of the Himalayan mountain system. From the gently curving arc formed by the Hindu Kush and Karakoram ranges of the northern Himalaya, the radius of curvature decreases southward to only a few miles at the syntaxial bend proper.

The Hazara-Kashmir syntaxis is oriented slightly west of north; it contains younger rocks in its core or axial zone and successively older rocks around the periphery. A system of boundary faults, which separates groups of geologic units, follows around the syntaxis and helps to define it.

Deformation in the early stages of the Himalayan orogeny is pictured as a general southward movement away from the central axis of the rising Himalayas. On the assumption that tectonic transport was perpendicular to the great regional arc of the Hindu Kush–Karakorum ranges, the lines of tectonic transport would converge on the present position of the Hazara-Kashmir syntaxis, which occupies the pivot point of the arc. Such movement from the northeast, north, and northwest, focusing on the present location of the Hazara-Kashmir syntaxis, eventually would cause the geologic structures and rock units to wrap around a core zone, compress the rocks within the core zone, and result in a structure such as the present syntaxis.

On the eastern, longer limb of the syntaxis, southwestward tectonic transport toward the axial zone has been demonstrated by Wadia [59] who mapped a system of thrust and reverse faults in the Pir Panjal range west and southwest of Srinagar.

On the western limb of the syntaxis, where most of the recent work was done, two main phases of deformation are indicated. The first movement was to the south together with a strong component of movement to the east and southeast as the southward-moving rock masses impinged against the early-forming axial zone of the syntaxis. This phase produced combined left-lateral and west-over-east reverse movments along the boundary faults, as well as north-dipping thrust faults and north-trending mineral lineations.

The second phase was a westward countermovement of rocks in the axial zone, manifested in the westward overturning of major folds along the western limb, and east-over-west displacement of younger over older rocks along the main boundary faults. The second phase is interpreted as an extrusion (regurgitation) upward and westward of the highly compressed rocks in the axial zone of the syntaxis in response to the prevailing southwestward movement of the rocks on the longer eastern limb of the syntaxis.

Wadia's generally accepted hypothesis [59] that southward-moving rock masses wrapped around a basement buttress is doubted because the axial zone, occupied almost throughout by a great thickness of upper Tertiary rocks, would seem to indicate a deep structural trough, rather than a basement high. Carey's hypothesis,[60] that a left-lateral couple between the Himalayas and the mountains of Iran produced the syntaxis, also is doubted, because other large reentrants in the system do not have the required sense of rotation.

Study of iron ores

A study of the mineralogy and genesis of iron-rich sedimentary deposits near Kalabagh, West Pakistan, has been described by J. J. Matzko (USGS) and Mahnoon Hasan, Geological Survey of Pakistan. The iron-rich beds are in the Chichali Formation of Cretaceous age at Chichali and Makarwal in the Mianwali and Kohat Districts. The bed at Makarwal, where mining of overlying coal is in progress, is 15 feet thick and contains from 21 to 32 percent total iron. At Chichali the ore bed is about 10 feet thick and contains an average of 32 percent total iron. The iron-rich beds

[59] D. N. Wadia, 1931, Syntaxis of the northwest Himalaya, its rocks, tectonics, and orogeny: India Geol. Survey Recs., v. 65, pt. 2, p. 189–220.

[60] S. W. Carey, 1958, A tectonic approach to continental drift—continental drift, a symposium: Univ. Tasmania Geol. Dept., p. 177–355.

range from glauconitic sandstone to glauconitic and ferruginous mudstone; siderite is the principal matrix material. Glauconite and siderite have been altered to goethite, and glauconite also breaks down to a siderite-like carbonate. Other minerals in trace to minor amounts are gypsum, microcrystalline hematite, microcline, muscovite, and an unidentified opaque mineral that forms thin coatings between grain boundaries. Much of the siderite in the deposit seems to be an original precipitate deposited at the same time as the glauconite.

The authors correlate variations of mineralogy with results of differential thermal analysis of the ore. They recommend this method as a rapid means to determine major mineral constituents for correct evaluation and metallurgical treatment.

SAUDI ARABIA

Mineral-reconnaissance reports

The first phase of the U.S. Geological Survey's mineral reconnaissance of the Arabian Shield area (about 600,000 sq km), financed entirely by the Saudi Arabian Government, has been completed. Its purpose was to make a rapid appraisal of mineral potential and delineate areas and individual deposits that merit additional, more detailed studies. The second phase is now under way and consists of exploration and evaluation of individual deposits and areas by detailed geologic mapping, geochemical and geophysical surveys, and, in some places, drilling.

The results of the first phase are given in about 100 administrative reports, which have been transmitted to the Saudi Arabian Government. Most of the reports consist of 1 : 100,000-scale 30′ by 30′ geologic quadrangle maps and accompanying text, but about 25 reports discuss specific mineral deposits or mineralized areas. These include deposits of tungsten, phosphate, barite, allanite, iron, pyrite, and gossan, as well as reports of geophysical and geochemical prospecting in specific areas. Of these administrative reports, 20 to 25 reports of economic or regional significance will be published by the Saudi Arabian Ministry of Petroleum and Mineral Resources.

Mineral reconnaissance

Richard Goldsmith (USGS) has completed mineral reconnaissance of the Southern Hijaz quadrangle in Saudi Arabia. The most important result of the work was the discovery of large areas of tungsten-bearing rocks in the mountainous region south and southeast of At Ta'if and in the Al Lith–Hajrah area 75 to 100 km to the south. Marble and kyanite deposits of possible economic value were also found in the Al-Lith area. Althogether, an area of about 10,000 sq km, including the intervening unexplored region between these two areas, is inferred to contain tungsten-bearing rocks and should be prospected in detail.

Copper, silver, gold, zinc, lead, and minor amounts of molybdenum minerals are present in a group of ancient mines and prospects in a zone 10 km long at Mahd adh Dhahab. Copper, zinc, lead, and molybdenum anomalies were also found in the southeastern section of the quadrangle, particularly along Wadi Bidah. Possibly a number of these closely spaced prospects collectively could be exploited successfully for copper, gold, silver, zinc, lead, and molybdenum, but none appears to be economic individually.

Disseminated copper is also present at Jabal Sumran and Umm ad Damar. Silver is more widely distributed than gold and is most abundant in the southeastern corner of the quadrangle. Possible exploitable deposits of niobium, thorium, and associated elements have been found at Jabal Sayid north of Mahd adh Dhahab.

Other interesting deposits of metallic and nonmetallic minerals have been found at several locations. Barite is present near Rabigh, and magnesite is present at Jabal Rakham and many also occur in a belt of similar rocks near Bi'r Umq, north of Mahd adh Dhahab, and near Jabal Farasan, southeast of Rabigh. Fifty million tons of oolitic hematite containing 44 to 50 percent iron is inferred in Tertiary beds east of Jiddah, and similar beds are poorly exposed in the upland plateau west of Turabah. A sizable deposit of talc lies northeast of Jabal Awf in the northwest corner of the quadrangle. Supplies of gypsum are available from Tertiary beds near Jiddah, and building stone, including marble, is present in abundance.

Bedrock of the southern Hijaz quadrangle consists mostly of crystalline rocks of Precambrian and early Paleozoic age that are part of the Arabian Shield. Subordinate Tertiary sedimentary rocks and extensive Tertiary and Quaternary basalt flows cover parts of the crystalline rocks. Metallic and nonmetallic minerals of economic importance are found both in the older crystalline rocks and in the younger rocks.

C. L. Hummel has found that in the northeastern Hijaz region of Saudi Arabia nearly all the gold-silver–base-metal lodes and ancient mines are closely associated with two geologic features: (1) marginal parts of many syntectonic granite masses (700–750 m.y. old) and adjacent metamorphic rocks of the Halaban Formation and (2) late Precambrian strike-slip faults. Because of the striking physical similarity and simple composition, it is likely that all the deposits formed during a single, long-term period of hydrothermal mineralization localized mainly along wrench faults where they transect the margins of the older granite masses. Thus, both the regional and local geologic controls are structural in origin. With these ideas as guides for subsequent mineral reconnaissance, Hummel found numerous mineral deposits and ancient gold and silver mines in several areas where they had not been known in recent times, thus greatly increasing the area in the northern Arabian Shield that is known to contain mineral deposits.

Investigation of phosphate deposits

Following identification of phosphate rock by R. P. Sheldon near the Trans-Arabian pipeline, studies by J. W. Mytton and Charles Meissner have resulted in the discovery of phosphate at three locations in the Jawf-Sakakah seidmentary basin of northern Saudi Arabia: in the Turayf area on the northeast side of the basin, at Thaniyat Turayf in the southwest quadrant, and at Al Jawf on the southeast side. The deposits are of Late Cretaceous, Paleocene, and Eocene age and are believed to represent a transgression of the phosphate-depositing sea into Saudi Arabia from Jordan, Iraq, and Syria, where Upper Cretaceous phosphate deposits are known.

In the Turayf area the phosphate occurs within a sequence of limestone, chalk, marl, cherty limestone, gypsiferous limestone, and chert. Found chiefly, as float, it has been traced more than 90 km in a north-south belt that ranges from 1 to 20 km in width. Test wells drilled by the Arabian-American Oil Co. indicate a phosphate-bearing layer at least 270 feet thick in the upper part of the Hibr Formation. Within this interval are several lenticular beds of phosphate rock 6 feet or more in thickness. Two kinds of phosphate rock, which consists of fine to medium-sized oolites, have been distinguished, depending on the cementing material. One type is a light-colored, medium-hard calcareous variety, and the second is a darker, hard, cherty variety. The lighter-colored variety is richer in phosphate; samples average about 19 percent P_2O_5 and contain as much as 23 percent.

In the Thaniyat Turayf area, phosphate-bearing rocks have been traced for about 100 km. Rocks believed to be in the Aruma Formation contain an average of 12 feet of alternating crinkly shale, sandstone, and silty marl to marly siltstone with sparse to abundant phosphatized pellets, oolites, fossil remains, and lithic fragments. The sequence averages 15 percent or more P_2O_5, and some layers ranging in thickness from 1 to 3 feet contain as much as 36 percent P_2O_5. Much of this phosphate rock is poorly consolidated, which will facilitate benefication. In the Hibr Formation in the same locality two or three lenticular beds of friable phosphate rock range in thickness from a few inches to 3 feet. One sample contained 32.4 percent P_2O_5, and others contained as much as 27.5 percent.

Layers of phosphate rock have been identified in both the Hibr and Aruma Formations for a distance of more than 40 km in the Al Jawf area. Individual layers 5 feet thick or less are composed of calcareous and cherty phosphate rock and phosphatic shale. The P_2O_5 content is generally low, but one layer was reported to contain 20 percent.

A detailed investigation of the phosphate deposits in the Jawf-Sakakah basin, including core drilling, is under way to determine the extent and grade of the deposits. The phosphate deposits in the southern part of the basin have been described in an open-file report by J. W. Mytton (r2104).

SPAIN

Basalts are principal sources of ground water in Canary Islands

According to R. J. Dingman the surface-water resources of the 7 principal islands of the Canary group have been fully developed by some 98 dams, 15 m or more high, as well as by thousands of small reservoirs. Ground water in all the islands occurs principally in basalts and to a lesser extent in associated pyroclastics, and is developed by means of some 3,625 dug wells, 962 infiltration galleries, and 221 springs. In some of the islands, notably Gran Canaria and Tenerife, ground-water levels are declining very rapidly because of increasing withdrawals. In Gran Canaria, for example, water levels have declined as much as 120 m during the past 40 years.

THAILAND

Reports of minerals investigations

Deposits of porphyry copper, barite, gypsum, and other minerals are described in a 276-page report that has been transmitted to the United Nations for publication. The report, by H. S. Jacobson and C. T. Pierson (USGS) and geologists of the Royal Thai Department of Mineral Resources (DMR) is the result of a 3½-year minerals investigation in northeastern Thailand sponsored by the United Nations. During the course of the investigation 58 mineral prospects were investigated by geological, geophysical, and geochemical methods and by pitting, exploratory mining, and diamond drilling.

Two copper deposits, Phu Hin Lek Fai and Phu Thong Daeng, are probably the most promising for mining in the near future. Drilling at Phu Hin Lek Fai has shown the presence of low-grade copper-bearing volcanic rocks in a zone having a width of 64.6 m and an average depth of at least 170 m. Electromagnetic and induced-polarization surveys indicate a strike length of more than 550 m. Proven and probable reserves are therefore about 15 million tons; they contain about 1 percent copper. Possible reserves at Phu Hin Lek Fai and in the adjoining Phy Hin Lek Fai north prospect are tentatively estimated at 50 million tons. Preliminary drilling and other related investigations indicate that the Phy Thong Daeng deposits may be the porphyry-copper type in volcanic rocks. One million tons of proven and probable reserves is estimated to be present in a zone 150 m long, 60 m wide, and 45 m thick. On the assumption of a strike length of 800 m (as indicated by surface gossan exposures), a width of 140 m, and a thickness of 45 m, additional possible reserves are 11.6 million tons; these reserves contain about 1 percent copper.

A deposit of barite called Bau Hin Khao may have possibilities for commercial development, if markets and transport facilities are developed. The deposit has a strike length of 1,200 m. Proven and probable reserves of massive barite are about 2.5 million tons. Partial analytical results indicate that the massive barite contains approximately 93 percent $BaSO_4$. It occurs in association with a sequence of limestone, shale, tuff, and dolomite beds, and is present as bedded replacement deposits in the dolomite. In addition, there are other low-grade reserves of barite with dolomite as well as boulders of barite in the soil, containing about 81 percent $BaSO_4$; additional possible reserves are conservatively estimated to exceed 3 million tons.

Small deposits of high-grade antimony ore in several provinces of northwestern and southwestern Thailand have been described by L. S. Gardner. Most, if not all, of the deposits are veins and are associated replacement deposits formed by hydrothermal solutions that moved along faults and fractures. Antimony sulfide (stibnite) was deposited at relatively low temperatures as fillings in fractures and interstices and as replacements of the country rock, generally in brecciated quartzite, sandstone, siltstone, shale, limestone, and granite. The grade of the ore ranges from a few percent of antimony to almost pure stibnite in some places.

The antimony deposits have been found in a large belt at least 1,200 km long and as much as 100 km wide in western Thailand. It is probably a southerly extension of a great mineralized belt in southern China that contains most of the world's reserves of antimony and tungsten. The rocks, structures, and late geologic history are similar throughout these two regions, which apparently form a single large metallogenetic province.

Little is known about the total antimony reserves in Thailand, because much of the country has not been mapped or studied in detail. Most of the deposits described by Gardner are small discrete bodies of limited areal and vertical extent and the ore is being exploited as it is discovered. However, the production from one mine in the Ban Song district of southern Thailand has vaulted Thailand into sixth place among world antimony producers.

TURKEY

CENTO training

The first of several planned annual CENTO training courses in geological mapping techniques was conducted from July 5 to September 10, 1966, under the supervision of E. H. Bailey (USGS) assisted by D. H. Kupfer (Louisiana State University), J. W. Barnes (University College of Swansea, England), and Allan James (Kennecott Copper Corp.). The course was held chiefly in northern Turkey, where the Kure cuprous pyrite deposits were mapped, and briefly in central Turkey, where parts of the Turhal antimony mine were mapped. Fourteen trainees from Turkey, Iran, and Pakistan were given instruction in surface and underground geologic mapping, using plane-table and other methods. Geochemical prospecting techniques, and various means of sampling and calculating reserves, were also taught.

The main ore body in the Kure district, which is now being mined, is a sulfide replacement of pillow lavas and associated graywacke and argillite. The ore formed in a small isolated unit of volcanic rocks within a folded and faulted sedimentary sequence as a blanket-like replacement beneath a hanging wall of argillite. The main controls that localized it are closely spaced joints in individual pillows, which provided easy access to mineralizing fluids, and the impervious character of the argillite that partly confined and guided the rising fluids. The ore consists of massive sulfides, chiefly pyrite with some chalcopyrite and a little bornite. The massive ore grades downward and outward from the hanging wall into more disseminated sulfide. The copper-rich parts of the ore body are close to the hanging wall. Gossan, while present, does not appear to have ever been extensive, and it passes abruptly into primary sulfide with almost no secondary zone. A second, much smaller, ore body shows some similarities to the main body in that it lies in lavas abutting argillite. A third ore body, of considerable size but not investigated in detail, is also in mafic volcanic rock but at a different stratigraphic horizon. Although it is adjacent to ores mined hundreds of years ago, it was only recently discovered by drilling and is not wholly explored.

The Turhal antimony mine, another one which was being operated recently, contains veins of quartz and stibnite in Paleozoic schist and greenstone. The veins range in thickness from less than 1 inch to more than 6 feet. They average about 4 percent antimony, but contain local pods consisting of pure stibnite.

REGIONAL FERTILIZER RAW-MATERIALS RESEARCH

South American regional fertilizer research

Because of concern over the need to increase food production in South America, a fertilizer raw-material research program has been underway since September 1965. The U.S. Geological Survey has provided technical services for the U.S. Agency for International Development and several international agencies, most notably the Inter-American Development Bank, the Organization of American States, and the Inter-American Committee on the Alliance for Progress.

Available information on the geology and resources of fertilizer minerals in most South American countries has been summarized in a recent report by J. F. Harrington and others (r0017). The report describes the minerology, geology, and technology of phosphate, potash, and sulfur deposits, and discusses the types of studies needed to fully assess the fertilizer mineral potential of South America. The report has been reviewed by the Inter-American Committee for the Alliance for Progress as a basis for a possible regional fertilizer exploration and development program.

INVESTIGATIONS OF PRINCIPLES AND PROCESSES

A substantial part of the U.S. Geological Survey research program is primarily topical and involves the application of principles and analytical techniques largely developed in the laboratory to elucidate the composition, structure, and evolution of the earth as a whole, its rocks and minerals, constituent elements, waters, and 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 the 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. Studies of the stability relations and isotopic compositions of minerals have given insight into ore-forming processes and have provided new guides for finding ore. Studies of the liquid inclusions in minerals have given new insight to composition of ore-forming solutions. Many new analytical techniques and methods, of wide application both within the Geological Survey and without, have been developed in the fields of wet chemistry, emission spectroscopy, mineralogy, X-ray spectrometry, electron-microprobe studies, and neutron activation studies, as well as new analytical techniques for use in searching for small amounts of heavy metals. Techniques that were little used a decade ago are now being developed or modified to be applied to the ever-changing requirements of earth-science investigations. Analytical services and research in these fields and in the fields of paleontology and geochronology are available to the Geological Survey as a whole.

PALEONTOLOGY

Paleontologists of the U.S. Geological Survey are engaged in a variety of research projects, all contributing to a synthesis of the evolution of marine and terrestrial biologic communities through geologic time. Detailed results of biostratigraphic, taxonomic, and phylogenetic studies are applied to specific geologic problems that arise from the Survey's geologic mapping program. The ultimate goal is a clearer understanding of the growth and development of North America and its surrounding oceans. Some of the significant advances in paleontologic research during the past year, many not yet published, are summarized below by major geologic age and area.

PALEOZOIC OF THE EASTERN STATES

Cambrian mollusks reevaluated

Morphologic studies of new salterellid material from southern Pennsylvania by Michael Taylor and E. L. Yochelson provide a framework for new phylogenetic interpretations. A gradual evolutionary change from a nonseptate, siphunculate conch (some salterellids) to a shell with very short, close-spaced septa (some salterellids and *Volborthella*) to a nautiloid-like septal plan (*Vologdinella*) is suggested. This change took place during the latter part of the Early Cambrian and early Middle Cambrian and clearly has bearing on the origin of nautiloid cephalopods.

New light on early pelecypods

The acid etching of 7 tons of silicified Ordovician limestone from the Cincinnati arch region has yielded large numbers of well-preserved specimens of many hitherto poorly known pelecypod species. This material provides the first good insights into the details of morphology, taxonomy, phylogeny, and stratigraphic distribution of these early pelecypods, according to John Pojeta. Some of the paleontological results include: good documentation for the splitting of the broadly defined nuculoid genus *Ctenodonta*, the establishment of a probable relationship between the seemingly distinct families Lyrodesmatidae and Cycloconchidae, and the observation that even at this early stage in their history pelecypods had diversified into six or more distinct ordinal-level taxa. In addition, the pelecypod genus *Cleionychia* has been identified from the Ordovician in the Cincinnati arch in Kentucky for the first time in a collection of silicified material from the Tyrone Limestone. Although this genus is most conspicuous in Middle Ordovician faunas of the northern Appalachians, Pojeta's studies indicate that the Kentucky specimens are more nearly similar to an unnamed species figured by Butts from the "Lowville" of Virginia.

Ordovician bryozoans from Kentucky

O. L. Karklins has completed an analysis of the bryozoans from the Antioch Church Road section in the Valley View quadrangle of Jessamine County, Ky. The assemblage of bryozoans from the upper 90 feet of the Lexington Limestone and the lower few feet of the overlying Clays Ferry Formation seems to be a transitional one that represents a change from older strata into lower Eden equivalents as they are understood in the Cincinnati area. The genera *Eridotrypa*, *Heterotrypa*, and *Hallopora* show evolutionary lineages that, when described statistically, may better document the biostratigraphic subdivisions of the Upper Ordovician.

Kentucky Ordovician brachiopods

R. B. Neuman's application of current concepts of dalmanellid genera to Ordovician brachiopods from Kentucky belonging to this group indicates that most of them should be reassigned to *Dalmanella*. However, a large dalmanellid from the Grier Member of the Lexington Limestone is a new species of *Heterorthina*. The Grier also contains silicified specimens of a strophomenoid identified as a new species of *Pionomena* with structures that relate this genus to *Fardenia*.

Silurian conodonts from Kentucky

J. W. Huddle has completed an analysis of Silurian conodonts from a detailed section sampled by G. C. Simmons in the Palmer quadrangle, east-central Kentucky. Sixty-nine samples from the base of the Brassfield Formation well up into the Estill Shale Member of the Crab Orchard Formation were studied, and Huddle reports the presence of all three of Walliser's Silurian conodont zones. Zone I occurs in the Brassfield and lower part of the Crab Orchard Formation (including the Plum Creek Member and the lower part of the Oldham Member). Zone II, previously reported as missing by Rexroad,[61] occurs in the Lulbegrud Shale and Waco Members of the Crab Orchard and, possibly, in the base of the Estill Shale Member. Zone III is represented by most of the collections from the Estill. No unconformity represented by the absence of Zone II is indicated.

Devonian coral assemblages

W. A. Oliver, Jr., has completed a summary report on the succession of Lower and Middle Devonian coral assemblages in eastern North America. Four distinct assemblages are known in the Helderberg Stage; three of these are widespread in distinct lithofacies. A middle Onesquethaw assemblage is known over a large area in rocks of varied lithologies; late Onesquethaw assemblages are mainly in limestone. Sequences of coral zones are similar in New York, Ontario, Ohio, and Kentucky and are of use in detailed correlations within the eastern half of North America.

Fayetteville fossils redescribed

A restudy of type material of G. H. Girty's new genera and species of invertebrate fossils from the Fayetteville Shale (Upper Mississippian) of northwestern Arkansas and northeastern Oklahoma is nearing completion. Girty described more than 110 taxa in 1910,[62] but neither figured the fossils nor cited localities from which they had been collected. The revision of these fossils is being undertaken by a group of specialists headed by Mackenzie Gordon, Jr., who is revising the brachiopods and trilobites. Associated with him are: W. J. Sando, corals; John Pojeta, pelecypods; I. G. Sohn, ostracodes; E. L. Yochelson, gastropods; and F. J. Collier (U.S. National Museum), bryozoans.

PALEOZOIC OF THE WESTERN STATES

Paradoxidid trilobite from Middle Cambrian of Nevada

A. R. Palmer has identified a fragmentary but recognizable representative of the genus *Centropleura*, a cousin of *Paradoxides*, in a collection by J. H. Stewart from Lander County, Nev. The genus is known elsewhere from northwest Europe, eastern Canada, Australia, and the Soviet Arctic. This is the first record of this widespread Middle Cambrian trilobite group in western North America.

Nevada Ordovician brachiopods

Brachiopods collected from the highest beds of the Antelope Valley Limestone (Pogonip Group) in the west-central Pahranagat Range in Lincoln County and in the Egan Range south of Ely, in White Pine County, Nev., demonstrate that these beds are of Marmor (Chazy) or somewhat younger age. Genera identified by R. J. Ross, Jr., include *Glyptorthis*, *Plectorthis?*, *Sphenotreta*, *Dactylogonia*, and *Macrocoelia*. Correlative beds to the west, in the Copenhagen Formation, are composed mainly of calcareous siltstone and some sandstone. To the east, correlative strata are probably to be found in the Eureka Quartzite. The most complete stratigraphic sequences in limestones of earliest Ordovician to mid-Middle Ordovician age in North America lie in the area between and adjacent to the

[61] C. B. Rexroad, E. R. Branson, M. O. Smith, Charles Summerson, and A. J. Boucot, 1965, The Silurian formations of east-central Kentucky and adjacent Ohio: Kentucky Geol. Survey, Ser. 10, Bull. 2, 34 p., 2 figs.

[62] G. H. Girty, 1910, New genera and species of Carboniferous fossils from the Fayetteville Shale of Arkansas: New York Acad. Sci. Ann., v. 20, no. 3, part 2, p. 189–238.

Pahranagat and Egan Ranges. The apparent absence of brachiopod assemblages whose ages fall within this time span, but whose occurrence is limited to more westerly areas like the Toquima Range, is attributed to some sort of environmental control.

Pogonip Group ostracodes

The Kanosh Shale of Hintze (1951) [63] of the Middle Ordovician Pogonip Group appears to contain three distinct ostracode zones, according to Jean Berdan's analysis of collections made by L. F. Hintze from the Ibex section, Millard County, Utah. The highest zone, which extends into Hintze's overlying Lehman Formation, also occurs in the upper part of the Antelope Valley Limestone in Nevada. The middle zone has also been found as far west as Nye County, Nev., in the Antelope Valley Limestone. The lowest zone, not as yet found in Nevada, occurs also in the lower member of the Swan Peak Formation near Logan, Utah. These ostracode zones should be useful for correlations between Utah and Nevada sequences within the Pogonip Group where other fossils are wanting or nondiagnostic.

Monograptus from Nevada

A new Early Devonian subspecies of *Monograptus hercynicus* has been described from two localities in northeast Nevada by W. B. N. Berry (p. B26–B31). One locality near Carlin is in Western assemblage rocks. The other, in Coal Canyon, Simpson Park Mountains, is in Eastern assemblage rocks. The graptolite indicates a Siegen age for the beds from which it came. The new subspecies is wider than European members of the species but is similar in other morphologic characteristics.

Oldest land plants in North America

The occurrence of the newly described species *Monograptus thomasi* Jaeger in association with branching vascular plants on northeastern Noyes Island, southeastern Alaska, has been confirmed by Dr. Hermann Jaeger as the same as that associated with the *Baragwanathia* flora in Australia and is considered to be the oldest record of land plants in this hemisphere. Further work on these assemblages is being pursued in cooperation with S. H. Mamay and with F. M. Hueber (U.S. National Museum). The vascular plants submitted by Michael Churkin, Jr., and G. D. Eberlein were identified as primitive psilophytes, indicative of earliest Devonian age. Because the plants are associated with invertebrates, including pragtolites, suggestive of specific affinity with Australian Lower Devonian forms, the combined biota provides a basis for transoceanic correlations.

New data on Nevada Devonian

Devonian marine and probable land-laid or estuarine facies rocks have been mapped by C. W. Merriam in the Cockalorum Wash quadrangle for 12 miles along the axis of the Fish Creek Range in central Nevada. Apparently the same unit has been mapped in northern Nye County reconnaisance by F. J. Kleinhampl and J. I. Ziony through a southern extension of this belt in the Hot Creek Range for another 35 miles. Coral patch reefs or bioherms of Merriam's Devonian Coral Zone F are scattered at different places in this formation, which also includes black carbonaceous shale, siltstone, and subordinate chert. Abundant spores and other organic remains suggest that these strata are partly land laid or estuarine. The sequence in Cockalorum Wash quadrangle may be partly equivalent to the Woodruff Formation of J. F. Smith and K. B. Ketner in the Carlin area.

Coral Zone F of the Great Basin coral sequence, considered of late Eifelian age, is probably the interval of greatest colonial coral development and potential reef building throughout the entire Cordilleran belt. The characteristic biohermal facies (Coral Zone F) of the west-central Great Basin, as represented at Lone Mountain and in the Cockalorum sequence, is the *Hexagonana-Sociophyllum* facies with *Australophyllum* and *Billingsastraea*-like genera, *Utaratuia*, *Peripaedium* and *Digonophyllum*, together with the youngest tabulate genus *Heliolites*.

Siphonodella in northern Rockies

The first record of the *Siphonodella sulcata* Zone of Collinson and others [64] in the northern Rocky Mountains region was reported by C. A. Sandberg and Gilbert Klapper in a study of the conodont zonation and facies relations of transgressive marine rocks that straddle the Devonian-Mississippian boundary in Wyoming and Montana. The fauna recovered from this lowermost Mississippian zone at Windy Gap in the Washakie Range, Wyo., provides firmer correlation between the basal part of the type Mississippian of the Upper Mississippi Valley and the basal part of the Lower Carboniferous of Germany. The conodont zonation proposed by Klapper (r2107) for the Lower Mississippian of Montana and Wyoming has been revised to include, in ascending order, the *Siphonodella*

[63] L. F. Hintze, 1951, Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geol. Mineralog. Survey Bull. 39, 100 p.

[64] Charles Collinson, A. J. Scott, and C. B. Rexroad, 1962, Six charts showing biostratigraphic zones and correlations based on conodonts from the Devonian and Mississippian rocks of the Upper Mississippi Valley: Illinois Geol. Survey, Circ. 328, 32 p., 6 charts.

sulcata (lower cuI), *S. sandbergi–S. duplicata* (upper CuI), and Lower *S. crenulata* (lower cuII *a*) Zones.

Mississippian Foraminifera zones

Fourteen biostratigraphic zones based on calcareous Foraminifera, representing Mississippian faunas ranging in age from late Kinderhook through Chester in North America, have been established by B. L. Mamet (University of Montreal) and B. A. Skipp and are correlated with Lower Carboniferous zones based on Eurasian faunal successions. Differences between the Eurasian and North American faunas are due chiefly to impoverishment of the latter in both genera and species. However, more than 100 cosmopolitan genera and species permit recognition of phylogenic bursts and similar range zones over much of the northern hemisphere. These cosmopolitan taxa suggest the following correlations between the Mississippi Valley sequence and the Tournaisian, Viséan and Namurian of France and Belgium: (1) uppermost Kinderhook extends up to the base of the middle Tournaisian; (2) Tournaisian-Viséan boundary corresponds to the Osage-Meramec boundary as defined by the type sections of the Keokuk Limestone and the Warsaw Limestone; (3) Viséan-Namurian boundary corresponds to the boundary between the Golconda Formation and the Glen Dean Limestone. Lower Carboniferous calcareous Foraminifera are potentially important biostratigraphically because they exhibit similar evolutionary patterns on an worldwide scale, because they evolved rapidly, and because they occur in many different marine carbonate rock facies.

Redwall bryozoans described

A comprehensive study of the Bryozoa collected from the Redwall Limestone of northern Arizona by E. D. McKee, R. C. Gutschick, and associates was completed by Helen Duncan in 1966. This Early Mississippian (Osage) bryozoan fauna consists of more than 30 species belonging to at least 19 genera and is considerably larger and more diversified than any Early Mississippian fauna hitherto recorded from the Western United States. Most of the species seem to be new. Only four, all Fenestellas, have close affinities with species described from the Osage Series of the Mississippi Valley region. Fenestellid bryozoans are one of the more prevalent faunal elements in the chert beds of the Thunder Springs Member of the Redwall. Locally in the Mooney Falls Member, folaceous fistuliporoids, compressed dendroid cryptostomes, and the free zoaria of the fenestellid *Lyroporella* are moderately abundant in oolitic and crinoidal limestones. The predominately fenestrate assemblages are interpreted to have lived loosely rooted on soft sediment. The faunules containing foliaceous, dendroid, and free zoaria apparently developed on a lime-sand substrate.

Permian floras from Texas

The first fossil plants from the Arroyo Formation of the Clear Fork Group (Leonard Series, Lower Permian) have been described by S. H. Mamay (p. C120–C126). The plants were found in a small shale deposit near Lake Kemp in Baylor County, Tex. The assemblage is limited and poorly preserved, but nonetheless it contains two taxonomic novelties: *Brachyphyllum* (?) *densum*, n. sp., and *Wattia texana*, gen., sp. *Brachyphyllum* (?) is obviously coniferous, but the affinities of *Wattia* are problematical. The flora is mixed, with indications of relationships to the Permian floras of Europe, Cathaysia, and Angaraland. The relatively high proportion of new taxa suggests that the Arroyo Formation may ultimately produce a diversified flora of much morphologic and phytogeographic interest. Mamay has also completed a study of *Russellites*, a new genus of Permian plants from the Belle Plains Formation of Baylor County, Tex. Exact affinities of *Russellites* are uncertain, but a noeggerathialean relationship is postulated. Previously described by Darrah [65] as an American *Tingia*, *Russellites* is so distinctive in its morphology as to be a potentially valuable index fossil.

MESOZOIC OF THE UNITED STATES

New Mesozoic pelecypods from United States

The pelecypod genera *Otapiria* Marwick and *Lupherella* n. gen., both resembling the late Triassic *Monotis*, are recorded for the first time from the United States by R. W. Imlay (r1420). Lupherella, from beds of Pliensbachian age in eastern Oregon and California, has not been found elsewhere. One species of *Otapiria* is from northern Alaska associated with or directly underlying *Inoceramus* cf. *I. lucifer* Eichwald, whose presence indicates an early Middle Jurassic or late Early Jurassic age not older than Toarcain. Another species has been found in float in east-central Alaska. Its age is unknown, but the presence of the crinoid *Pentacrinus subangularis* var. *alaska* Springer indicates that beds of Early Jurassic age are present. *Otapiria* has been found prebiously in Upper Triassic to Upper Jurassic beds in New Zealand, Lower Jurassic beds in New Caledonia, and Upper Triassic to Lower Jurassic beds in northeastern Siberia.

[65] W. C. Darrah, 1938, The occurrence of the genus *Tingia* in Texas: Harvard Univ. Bot. Mus. Leaflets, v. 5, p. 173–188.

Cretaceous of San Juan Basin, west-central New Mexico

Six distinctive macrofossil faunal zones of Graneros and early to middle Greenhorn age have been recognized by W. A. Cobban in collections obtained with C. H. Dane and E. R. Landis from the lower part of the Upper Cretaceous on the east side of the San Juan Basin, from the Rio Salado to La Ventana. Results of the study of 88 collections from 20 measured sections allow close correlation of faunal zones with the extensive sandstone bodies that have been variously classified as parts of the Mancos Shale, or as integral parts of the Dakota Sandstone. Extension of this information to the northeastern part of the San Juan Basin and the Chama basin, supplemented by microfossil identifications by J. F. Mello, indicates that the rock unit mapped there as the Graneros Shale Member of the Mancos Shale is practically all of early to middle Greenhorn age. Absence of the *Plesacanthoceras wyomingense* fauna, widespread in the northern part of the country, suggests an unconformity in the middle of the sequence in the San Juan Basin and southern Colorado.

New Mexico Cretaceous snails

Gastropods, potentially useful for correlation purposes, are reported by N. F. Sohl from samples collected at several localities in New Mexico by E. R. Landis and C. H. Dane. These specimens partially bridge the gap between Cretaceous deposits of the Gulf coast and the Western Interior, where critical gastropod information heretofore has been lacking. Evidence from the collections under study suggests that material from more control points may permit gastropods to be used with considerable precision in correlations between the two areas.

Foraminiferal parameters examined

A generic-level analysis of data presented by Cushman [66] on Cretaceous Foraminifera of the Gulf Coastal Plain has been made using conventional and statistical methods. On the basis of the data presented by Cushman it has been concluded that there is no consistent relationship of reasonable sample groups to geographic position, inferred stratigraphic position, or lithology. The relationships of the genera to each other vary from one formation to another. This may be explained as a lack of any generic-level adaptation to environment, to a lack of sufficient data to discern relationships which may exist, or, possibly, to shortcomings of the methods used.

[66] J. A. Cushman, 1946, Upper Cretaceous Foraminifera of the Gulf coastal region of the United States and adjacent areas: U.S. Geol. Survey Prof. Paper 206, 241 p.

New Cretaceous ammonites in Western Interior

Ammonites were discovered by W. A. Cobban in the middle of the Upper Cretaceous Belle Fourche Shale on the west flank of the Black Hills uplift in eastern Wyoming that are very closely related to some from the base of the Eagle Ford Shale of Texas. The ammonites, although represented by many specimens, consist of two species that differ little from *Acanthoceras stephensoni* Adkins and *Caylceceras leonense* (Adkins). In addition, invertebrate fossils of Cretaceous age collected by J. R. Gill and E. A. Merewether in the Wild Horse Mountain quadrangle, Carbon County, Wyo., included a cephalopod not previously found either in Wyoming or this far north in the Rocky Mountain region. The identification and unusual occurrence of *Baculites undatus* Stephenson?, a species adapted to the warm waters of the Gulf of Mexico, was suggested by Cobban.

California Mesozoic mollusks

The uppermost Jurassic is represented in California by species of the ammonites *Substeueroceras* and *Parodontoceras* that are closely similar to species in the highest Jurassic beds of Mexico and Argentina, according to R. W. Imlay. Ammonites such as *Spiticeras* (*Negreliceras*), *Neocosmoceras*, and *Subthurmannia* occur in the earliest Cretaceous (Berriasian) of California and southwest Oregon. These are associated with the characteristic Berriasian pelecypod *Buchia uncitoides* (Pavlow) and, rarely, with *B. okensis* (Pavlow).

MESOZOIC AND TERTIARY NONMARINE FOSSILS OF THE UNITED STATES

Age of Raton Formation

Both Cretaceous and Paleocene palynomorph assemblages have been identified by R. H. Tschudy, from the Raton Formation, Colfax County, N. Mex., in samples submitted by C. L. Pillmore. The Cretaceous assemblage is 265 feet above the base of the formation and the Paleocene occurs at 550 feet. The palynological evidence thus indicates that the Cretaceous-Paleocene boundary in Colfax County must be at least 265 feet above the base of the Raton Formation.

Paleocene fresh-water mollusks from North Dakota

Fresh-water mollusks collected by A. F. Bateman, Jr., from the Tongue River Member of the Fort Union Formation have been dated by D. W. Taylor as middle or, perhaps, early Paleocene in age. They can be correlated with the fresh-water mollusk faunal sequence of Wyoming and with the mammalian chronology of that region. Furthermore, an early or middle Paleocene date for part of the Tongue River Member provides additional evidence for dating the youngest marine fauna in the Western Interior, that of the underlying Cannonball Member. According to Taylor, the Cannonball Member is thus limited to about the earlier third or half of the Paleocene.

Dinosaurs in Yellowstone Park

First evidence that dinosaurs once roamed in what is now Yellowstone National Park is reported by J. D. Love who discovered a fragmentary tooth in the Harebell Formation. According to G. E. Lewis, this fragment probably is referable to one of the deinodont theropods (large bipedal carnivorous dinosaurs) of Late Cretaceous age.

Earliest nonmarine diatoms

In a restricted area on the Beaver Rim in central Wyoming, the lower Oligocene Beaver Divide Conglomerate Member of the White River Formation contains fresh-water limestone blocks eroded from the upper part of the middle and upper Eocene Wagon Bed Formation. Some of these limestone blocks contain a diatom assemblage which has been studied by K. E. Lohman and G. W. Andrews. This is the oldest nonmarine diatom assemblage known from North America. This late Eocene diatom assemblage contains 1 new genus, 27 new species, 2 species known previously from the upper Miocene of France, and 5 species which are still found in living assemblages. It is strikingly different from later Tertiary fresh-water assemblages in that many genera common to younger deposits are totally lacking. The assemblage may indicate that some of the common genera of fresh-water diatoms had not evolved by late Eocene time. Although these genera may be missing only because of a highly specialized paleoenvironment, sparse evidence provided by the five species that are still living suggests only that deposition occurred in a temperate, circumneutral lake.

Fruit and seed discoveries

Three plant genera of special interest have been identified by R. A. Scott in his continuing study of fossil fruits from the Eocene of Wyoming. *Chandlera*, an extinct member of the moonseed family whose closest modern relatives now grow in southeast Asia, has been found only once previously in the Eocene of Oregon. *Poupartia*, belonging to the sumac family, is an Old World genus never before found in the Western Hemisphere. Fossil hickory nuts, *Carya*, confirm the presence of this genus in the Eocene of Wyoming. Fossil pollen resembling this genus is conspicuous in many early Tertiary palynomorph assemblages in the Rocky Mountain area. Numerous fossil seeds obtained from a new locality in the Morrison Formation (Jurassic) of Utah now has confirmed the presence of a widespread, diverse, regional flora containing, in part, unusual cycadophytic plants. Study of fossil cone scales common to two seed-bearing localities has shown that the living coniferous genus *Araucaria*, rather than an extinct relative, lived during the Jurassic. Prior to the discovery of fossil seeds in the Morrison last year, its known flora consisted chiefly of fossil araucarian wood.

Tertiary floras of southern Alaska

Analysis of fossil leaf assemblages from Tertiary rocks in the Cook Inlet region and the central Alaska Range by J. A. Wolfe indicates that six assemblages of stratigraphic significance can be recognized from the middle Oligocene through the Pliocene. The oldest assemblage has been recognized in several parts of Alaska and includes plants from the Tsadaka and lowest part of the Kenai Formation in the Cook Inlet region. The next higher assemblage, not recognized in the Cook Inlet area, is present in the basal part of the coal-bearing rocks of the central Alaska Range. The four higher assemblages are present in both the Kenai Formation and the Tertiary rocks of the Alaska Range. The fossil plants indicate that the Alaskan climate was warm temperate from the middle Oligocene through about the middle Miocene; during the late Miocene, the Alaskan climate deteriorated to conditions similar to those of the present.

Late Cenozoic floras of Alaska Range

Description and dating of six Tertiary formations in the Nenana coal field of the Alaska Range has resulted from studies of: (1) stratigraphy by Clyde Wahrhaftig, (2) fossil leaves by J. A. Wolfe and (3) pollen by Estella Leopold. These rocks range in age from late Oligocene to youngest Miocene. The oldest formation can be divided on the basis of pollen and leaves into two members, the older of which is latest Oligocene in age, and the younger early Miocene in age. This formation contains by far the most diversified flora and includes several subtropical and very warm temperate forms (*Melia-Cedrella*, *Engelhardtia-Alfaroa*, *Itea*) as well as several extinct groups (*Aquilapollenites*, *Gynkaletes*, *Proteacidites globosiporus*). Three overlying formations contain a diverse flora of warm temperate broadleaved trees (*Carya*, *Juglans*, *Pterocarya*, *Ulmus*, *Tilia*, *Liquidambar*) as well as various conifers, but lack extinct forms. These rocks are of early, middle, and late Miocene age. The two highest units, an unnamed unit and the Nenana Gravel, contain a more impoverished and somewhat more cool temperate flora, though a few plants that now grow in warm temperate climates are present. These formations are of latest Miocene age, and the lower of these (the unnamed unit) has been dated by the K-Ar method as being at least 8 m.y. old. Pollen samples from the Nenana Gravel appear to contain some reworked pollen from older beds, but on the whole represent a flora dominated by plants that grow in Alaska today.

Mississippi Embayment pollen assemblages

Late Cretaceous and early Tertiary pollen assemblages from the Mississippi Embayment region have yielded at least 45 species belonging to the extinct plexus of genera known as the *Normapollis* group, according to R. H. Tschudy. These genera are common to the Late Cretaceous and early Tertiary of Europe but are very rare from rocks of equivalent age in the Rocky Mountains region. Twenty-two of these species are present in the Cretaceous, 24 are found in the Paleocene Midway Group, 8 in the Eocene Wilcox Group, 7 in the lower part of the Eocene Claiborne Group, and none in the upper part of the Claiborne or younger rocks of the Mississippi Embayment region. This group of distinctive genera had its origin in the Late Cretaceous, flourished during the Paleocene, began to die out in the Eocene, and became extinct by late middle Eocene (late Claiborne) time.

CENOZOIC OF THE UNITED STATES

Miocene paleoenvironments in San Joaquin Valley, Calif.

A warm pulse in the progressive Tertiary cooling trend of the shallow-water northeastern Pacific Ocean is suggested by paleoecologic study of Miocene molluscan faunas of the southern San Joaquin Valley, Calif., by W. O. Addicott. More than 35 percent of the 155 gastropod taxa in the middle Miocene Barker's Ranch fauna of the Kern River area are of warm-water aspect. Many of the genera and subgenera have not been reported previously from as far north as California. Early and late Miocene faunas from this part of California are of a cooler climatic aspect. The early Miocene fauna of the Kern River area, for example, includes only a small element of warm-water species, about 15 percent, and several species are known only from northerly, presumably cooler, localities along the Pacific coast.

Ostracodes in Brightseat Formation in Maryland

The large, well-preserved assemblages of ostracodes found in the Brightseat Formation in Maryland have permitted taxonomic reevaluation by J. E. Hazel of many of the older Tertiary genera occurring in North America. Some of the more commonly occurring species of brachycytherine ostracodes in the American Tertiary formerly assigned to *Brachycythere* do not belong to that genus. A new genus has been established for these forms, and the evolutionary development of the various species complexes has been traced from the Cretaceous to the Miocene.

New Tertiary correlations in California

Both benthonic and planktonic Foraminifera in rocks from the Big Pine Mountain quadrangle of the San Rafael Primitive Area of southwest California indicate an early Eocene or early middle Eocene age. R. L. Pierce's studies show that they can be assigned to Mallory's upper Penutian or lower Ulatisian Stages and would correlate with the upper part of the Anita Shale (as used by Kleinpell and Weaver[67]) of the western Santa Ynez Mountains. Previously, these rocks had been mapped as Upper Cretaceous by the California Division of Mines and Geology and as undifferentiated Eocene by the U.S. Geological Survey. The occurrence of *Uvigerina gallowayi* Cushman and *Siphogenerina multicostata* Cushman and Jarvis in the "lower Galloway Beds" (Kleinpell and Weaver, p. 43–69) in the Point Arena area, California, indicates that those rocks should be assigned to Kleinpell's upper Zemorrian or lower Saucesian Stages and not to Kleinpell's lower Zemorrian Stage. Although *Uvigerina gallowayi* Cushman has a stratigraphic range from lower Zemorrian to upper Saucesian in California and has been reported to occur in rocks assigned to the Refugian Stage of Schenck and Kleinpell, *Siphogenerina multicostata* Cushman and Jarvis only ranges from Kleinpell's upper Zemorrian to lower Saucesian Stages in California.

Paleocene microfossils from Kentucky

Foraminiferal and palynological studies by S. M. Herrick and R. H. Tschudy (p. B40–B44) suggest an early Porters Creek age for deposits in northern Ballard County, Ky. Comparison with microfaunas described from localities in the Gulf coast and Mississippi Embayment region indicates a horizon above the Clayton Formation and in the basal Porters Creek clay that is the equivalent to Plummer's "transition zone" and to Kellough's *Polymorphina cushmani* zonule in the basal Wills Point Formation (Paleocene of Texas).

Origin of sea lions postulated

Fossil sea-lion material, collected from several localities in the lower Pliocene(?) part of the Santa Mar-

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[67] R. M. Kleinpell and D. W. Weaver, 1963, Foraminiferal faunas from the Gaviota and Alegria formations, and their correlatives in the West Coast Ranges: Univ. California Pubs. in Geol. Sciences, v. 43, pt. 1, p. 1–80.

garita Sandstone and in the middle and upper Pliocene Purisima Formation in the area of Santa Cruz, Calif., appears to belong largely to a single new genus of marine mammals. Study of the fossils, now in progress by C. A. Repenning, has clearly shown that they belong to neither of the two living families which include the sea lions and the walruses. Rather they should be assigned to an extinct family, the Desmatophocidae, named by Hay in 1930.[68] Largely because of the abundance of fossils, completeness of skeletal parts, and excellence of preservation it is apparent that this extinct family is intermediate between sea lions and walruses in the structure of nearly all bones of the head and limbs; in all probability the group was ancestral to the living families. Repenning reports that many fossil pinnipeds, some described as sea lion and some described as walrus, from lower Miocene to upper Pliocene localities around the North Pacific from San Diego to Japan, belong in this ancestral family. Evolutionary stages are recognizable, and when lineages are defined it is expected that these animals will be as biostratigraphically useful in marine deposits throughout the North Pacific basin as land mammals are in continental beds.

OTHER PALEONTOLOGICAL STUDIES

Possible source of sedimentary carbonate particles

Cooperative research by I. G. Sohn and L. S. Kornicker (U.S. National Museum) indicates that the valves of myodocopid ostracodes, in common with the integument of other Crustacea, consist in part of monohydrocalcite ($CaCO_3 \cdot H_2O$). This was determined by E. H. Roseboom, Jr., using X-ray diffractometer methods. Upon death of the animal, the monohydrocalcite converts to calcite and forms microconcretions that may contribute a considerable volume to calcareous marine sediments.

Planktonic faunas from Cuba

A series of 35 samples from the Cretaceous and lower Tertiary of Cuba contain abundant well-preserved Radiolaria. Many of the samples also contain abundant planktonic Foraminifera. K. N. Sachs, Jr., regards this association of Radiolaria and planktonic Foraminifera as critical to the development of a biostratigraphic zonation based on the Radiolaria. These samples, collected by the late R. H. Palmer, were made available for study by Mrs. K. V. W. Palmer (director, Paleontological Research Institution).

[68] O. P. Hay, 1930, Second bibliography and catalogue of the fossil Vertebrata of North America: Carnegie Inst. Washington Pub. 390, v. 2, p. 557.

Variability in Tertiary larger Foraminifera

Suites of specimens of *Lepidocyclina (Eulepidina) undosa* Cushman and *L. (E.) yurnagunensis* Cushman from the Oligocene San Sebastián Formation of northern Puerto Rico and Juana Díaz Formation of southern Puerto Rico have been studied by K. N. Sachs, Jr. (r2109). He concludes that these species are highly variable and that Foraminifera of the subgenera *Lepidocyclina* and *Eulepidina* cannot be distinguished from each other by the appearance of a single feature. On the basis of additional studies of Foraminifera from Cuba, Panama, and the Gulf coast of the United States, he further suggests that environmental factors may cause considerable variability within individual species of Tertiary larger Foraminifera; recognition of this intraspecific variability should allow reduction in the number of specific names heretofore used.

New paleontological data from Cretaceous of Jamaica

Seven tons of fossils were collected by N. F. Sohl from selected measured sections in the central and western Cretaceous inliers of Jamaica. Here sequences of rudist- and nerineid-bearing limestones occur interbedded with shales that contain a varied molluscan shelf fauna that includes occasional ammonites and inoceramids. This association will allow refined determination of the ranges of many of the widespread rudist species and thus will aid interisland correlation.

Preliminary identification of nerineid gastropods from the limestones of the Benbow inlier suggest a late Barremian age for the Benbow Limestone. The older, underlying Copper Limestone has not yielded diagnostic fossils. Thus the Jamaican sequence possesses limestones older than those in the Puerto Rico section, where the oldest well-documented units are early middle Albian in age. Higher in the Jamaican sequence, preliminary field identifications of inoceramids and ammonites found in the *Inoceramus* beds of the central and St. Ann's Great River inliers and in the Hanover Shales of the Hanover and Westmoreland inlier indicate that at least parts of these units are of late Santonian to Campanian age rather than Cenomanian to Coniacian age as previously reported.

Age dilemma in Puerto Rico Trench

K. N. Sachs, Jr., reports 2 rock samples of different ages in a single dredge haul from a depth of 3,530 to 3,697 fathoms on the south slope of the Puerto Rico Trench. The samples were submitted by W. A. Berggren (Woods Hole Oceanographic Institution). One sample contains an upper Eocene association of *Lepidocyclina macdonaldi* and *Asterocyclina* cf. *A. minima*.

The other contains an upper Oligocene(?)-lower Miocene association of *Miogypsina* sp., *Lepidocyclina* sp. cf. *L. gigas* and *Numulites* (*Camerina*) *dia*. The latter sample resembles mid-Tertiary rocks found in Puerto Rico; the former seems most closely related to Eocene deposits of Cuba.

Radiolaria from sea floor

Radiolaria have been recovered from bottom sediments on the Mid-Atlantic Ridge in the area lat 22–23° N., long 45–46° W. by K. N. Sachs, Jr. Although moderate numbers of tests were recovered, very few species are represented and nearly all specimens show effects of solution. Comparison of this material with the rich radiolarian faunas from plankton samples in the same area supports the suggestion that collections of Radiolaria from bottom samples in this area are biased owing to removal by solution of many of the more delicate forms.

Tertiary fossils from Tongue of the Ocean

Two genera of planktonic Foraminifera have been identified by T. G. Gibson from a sediment sample taken at a depth of 5,500 feet by J. S. Schlee during a dive in the small submarine *Alvin* in the Tongue of the Ocean, off the Bahama Islands. The sediments indicate deep-water origin, and the fossils suggest an age of earliest Pliocene or, at the oldest, late Miocene. This is particularly significant because Eocene sediments were found at much shallower depths in the drill hole on nearby Andros Island.

Pacific islands mollusks

With the publication of "Chitons and gastropods (Haliotidae through Adeorbidae) from the western Pacific Islands", H. S. Ladd (r0895) has completed a major part of his life's work on mollusks from the western Pacific. More than 200 species are described, a majority of them from the Marshall Islands. Most of the mollusks were reef associated, and the richest and most widespread assemblages are Miocene. Many species occur in lagoonal beds, a fair number in beds that accumulated on tidal flats, and a few species lived in fresh or brackish waters. The assemblages of fossil mollusks, like those living in the area today, are Indo-Pacific in general aspect.

Tertiary faunas of Midway Atoll

A sedimentary section overlying basalt at Midway Atoll, penetrated and cored by two deep drill holes—one to about 600 feet and the other to about 1,200 feet, shows promise for establishing a sequence of microfaunas useful in the late Tertiary of the central Pacific, according to studies by Ruth Todd and Doris Low. The top of the Miocene (Tertiary *g*) is recognized by the occurrence of *Valvulammina marshallana* Todd and Post, and some accompanying species, at 445 feet in the Sand Island hole and at 500 feet in the Reef hole. This horizon in the Midway section can be correlated tentatively with levels in the Marshall Islands of about 800 feet in Eniwetok hole E–1 and about 850 feet in Bikini hole 2–B. A well-preserved assemblage of foraminifers at 1,045 feet contains the rare genus *Caucasina*, described originally from the Oligocene of the Caucasus region. The genus has been recorded from the Upper Cretaceous of Alaska and the Gulf coastal region and is known to range from Eocene to lower Miocene in France and the U.S.S.R. Just below this level, specimens of *Asterigerina marshallana* were identified; correlations can now be made with the well sections on Bikini and Eniwetok.

Another possible correlation point between the Midway and Marshall sections is a zone of densely packed specimens of the miliolid genus *Austrotrillina*. This occurs at 1,117 feet at Midway, between 1,835 and 2,000 feet at Eniwetok, and between 2,000 and 2,250 feet at Bikini. The occurrence of the genus *Austrotrillina* in the Hawaiian Islands is of particular interest because it extends the geographic range eastward. Its recorded occurrences are all in the Tethyan region and in the western and central Pacific. The genus is known only in the Oligocene and Miocene and has not been found in North or South America.

The earliest record of Foraminifera at Midway is at 1,165 feet, near the bottom of the Reef hole, where a meager fauna dominated by small specimens of bolivinids and buliminids occurs. The fauna, although not typical of that usually found around coral reefs, is probably Tertiary *e* (early Miocene) in age.

Possible Precambrian algae

Drag marks on bedding planes of fragments of the upper Precambrian Winnall Beds ejected from the Henbury meteorite craters in central Australia were shown by D. J. Milton (r0738) to have formed by the drag over the Precambrian sea floor of semibuoyant flexible objects at least 15 cm long. These were probably organisms, perhaps seaweedlike. Evidence for such organisms in the Precambrian has not been reported previously.

Antarctic paleobotanical studies

J. M. Schopf and party made studies of the contacts of the Whiteout Conglomerate with the overlying Polar Star Formation and the underlying Crashsite Conglomerate. Probably the most significant new observation relates to the facies similarity between the dark shales and tracks and trails of the lower part of the Polar Star Formation and the Discovery Ridge Formation of the Ohio Range. This correlation may be made over a distance of about 600 miles. Additional specimens of attached *Glossopteris* seeds were discovered. They are important in the interpretation of the phylogeny of these plants; a gymnosperm alliance of *Glossopteris* is strongly implied. Significant fossil plant material contributed by geologists of the Australian Department of Mines extends the known distribution of Triassic deposits and contributes additional elements to the Antartic Permian flora.

Permian fossils from Pakistan

Taxonomic and biostratigraphic analyses by R. E. Grant confirm the presence of six species of the brachiopod *Marginifera* and one of *Echinauris* in the Permian of the Salt Range, West Pakistan. These are the same species as those established by Waagen in 1884, pointing up the superfluity of all subsequent names published for species of these genera at this locality. Stratigraphic distribution of *Marginifera* supports other evidence for a Guadalupe, rather than Dzhulfian, age for the "Middle and Upper Productus Limestones." A subsequent interval of erosion or minimal deposition prior to Triassic sedimentation occurred in the area. R. C. Douglass, during examination of samples from the "Lower Productus Limestone" of West Pakistan, found the fusulinid genus *Codonofusiella* in rocks below strata of Early Permian (Wolfcamp-Leonard) age. This genus previously had been considered diagnostic of Late Permian (late Guadalupe) fusulinid assemblages.

Additional studies

Many paleontologic determinations are carried out by paleontologists of the Geological Survey in cooperation with Survey colleagues. The results of these investigations are reported elsewhere in this chapter and are generally listed in the index as entries "Paleontology" or "Stratigraphy" under names of States or areas.

MARINE GEOLOGY AND HYDROLOGY

Diversified investigations will continue on the geology and hydrology of the continental margins of the United States, including bays and estuaries, and on the Pacific islands and reefs. Geologic and geophysical investigations designed to locate and identify offshore heavy-metal deposits on the Pacific and Alaska Continental Shelves and to relate the deposits to the regional geologic and paleogeographic framework have measurably increased the marine activities of the U.S. Geological Survey on the west coast. Some of these investigations are carried out through research contracts with universities and institutions and by cooperative programs with the U.S. Bureau of Mines and other Federal agencies.

ATLANTIC CONTINENTAL MARGIN

Deep-sea research submersible

The highlight of marine activities on the Atlantic continental margin was three dives in the DSRV *Alvin* made by J. S. Schlee and J. V. A. Trumbull. The submersible was used to trace rock outcrops, to collect sediment and rock samples, and to photograph submarine canyon walls and the ocean floor. Successful color and black-and-white photography showed that small objects are easily distinguishable 8 to 10 feet away. Two dives were made in the Tongue of the Ocean near New Providence Island, Bahamas, and one dive was made in Oceanographer Canyon, southeast of New England.

The Oceanographer Canyon dive was to a depth of 4,800 feet in the axis of the canyon. A rock sample was taken from an outcrop at the base of the west wall of the canyon by the mechanical arm holding a rotating coring tube. The age of the outcrop was Pliocene or younger, indicating that the rock was probably a remnant of an earlier fill. Unconsolidated silty clay covered a 35°–40° slope for 150 m above the outcrop. Minor downslope transport of sediment was seen on the sidewall of the canyon. Rounded talus blocks lying on the flat sediment of the canyon floor well away from the sidewall indicate mass transport down the canyon axis.

The slopes of the Tongue of the Ocean in the Bahamas were 15°–70° and were too steep for the Alvin to land. Samples of calcilutic limestones were collected from a depth of 1,675 m and are about half magnesium calcite, about a third aragonite, and the rest low-magnesium calcite. They are composed of a poorly sorted mixture of pteropods, benthonic and planktonic Foraminifera, spines, and other debris set in a matrix of finer grained calcium carbonate. The unconsolidated sediment samples are similar in biogenic content and are much richer in aragonite and shallow-water Foraminifera. The limestones range in age from late Miocene to Recent.

Gulf of Maine

A heavy-minerals distribution study of the sand-size fraction of sediments from the continental margin off the northeastern United States has indicated 15 heavy-mineral provinces, according to D. A. Ross. Of these, 5 provinces are associated with present-day rivers, 5 have a glacial origin, 1 resulted from reworking of sediments by waves and currents, and 4 provinces on the flanks of Georges Bank resulted from erosion and transportation of fine-grained material. The mineral composition in each province is usually a function of the source, modified by selective sorting and weathering or diagenetic processes. Most of the sediments were dispersed in an offshore direction along the continental shelf and slope. Many of the dispersal patterns indicate the age to be Pleistocene.

The glaciated regions show highly variable textural patterns of bottom sediment. The patterns reflect Pleistocene glacial sedimentation and post-Pleistocene reworking and deposition and are related to the topography and types of glacial deposits, according to J. S. Schlee.

Trends in the size of gravel and loss of certain rock types indicate to J. S. Schlee and R. M. Pratt (Woods Hole Oceanographic Institution) that the ice moved into the Gulf of Maine in two main lobes—into the Great South Channel and into the Jordan Basin area. The major outlet for the ice was the Northeast Channel. Ice rafting carried erratics along the continental slope and rise into the deep ocean basin as far south as Hudson Canyon. The lack of shoals and rounded gravels indicates that the glaciers ended over the deep sea without reworking the gravel through river transport.

Submarine canyon extensions

R. M. Pratt (Woods Hole Oceanographic Institution) reports that a new submarine canyon system south of Sable Island off the northeastern coast of Nova Scotia has been discovered and named Sable Island Canyon. Major continuations down the continental rise have been found for Wilmington, Washington, Gilbert-Lydonia, and Corsair Canyons. These canyon extensions have a high-leveed right bank and bend toward the left where they enter the continental rise, with the exception of Wilmington and Hudson Canyons, which bend sharply to the right and become deeper about 70 miles down the continental rise. The outer gorges cut through an oversteepened part of the continental rise.

Two cycles of canyon formation are suggested by data obtained recently on the continental rise. Numerous canyons are present on the continental slope, but those having deep-sea extensions are probably related to major drainage areas on the east coast.

Mammoths and mastodons on the Atlantic Continental Shelf

A study of mammoth and mastodon teeth dredged off the floor of the Atlantic Continental Shelf was completed by F. C. Whitmore, Jr., and others (r2088). The mastodon teeth represent *Mammut americanum* (Kerr). They cannot be distinguished from mastodon teeth found on the mainland of the eastern United States. The mammoth teeth are very different from *Mammuthus primigenius* (Blumenbach), the woolly mammoth, *M. jeffersonii* (Osborn), and *M. columbi* (Falconer). Their tooth pattern is closer to that of the woolly mammoth than to that of the Columbian mammoth, and may signify a grazing habit. Tooth dimensions may indicate a smaller animal than the known mammoth species of the present North American mainland. The mastodons and mammoths inhabited what is now the continental shelf. According to K. O. Emery (Woods Hole Oceanographic Institution), the outer part of the continental shelf, during its last emergence, was exposed for about 10,000 years and the inner part for about 20,000 years, ending about 15,000 years ago.

PACIFIC AND ALASKA CONTINENTAL MARGIN

Submerged beach lines and drainage systems in Bering Sea

At least three sets of now-submerged beach lines were formed during stillstands of the late Wisconsin and Holocene rise in sea level and are widely distributed in the coastal waters off Seward Peninsula, according to D. M. Hopkins, A. R. Tagg, and Hans Nelson. The shallowest beach line can be identified on fathograms collected in Kotzebue Sound by the Geological Survey. All three can be recognized on the detailed bathymetric charts of waters adjoining Cape Prince of Wales, Cape York, Point Spencer, and an area west of Nome. Studies by the University of Washington in the Chukchi Sea indicate that the —38-m shoreline is between 12,500 and 14,500 years old. A single radiocarbon date at Nome suggests that the —20-m shoreline is older than 9,800 years and that the —10-m shoreline is younger. Onshore investigations done in conjunction with the offshore studies in southern Kotzebue Sound resulted in (1) recognition of local areas of late Pleistocene faulting and warping; (2) identification of the limits of spruce, birch, and alder, and of beaver during a warm interval 10,000–8,300 years ago; (3) identification of a spectacular group of maars or explosion craters near Devil Mountain, Seward Peninsula; and (4) identification of two widespread ash layers of late Wisconsin age that will furnish important marker horizons in future studies of cores from that area.

A newly recognized submerged drainage system can be identified on bathymetric charts and fathograms of the northern Bering Sea and Chukchi Sea. The drainage system includes minor tributaries that are continuations of small streams in coastal areas on land. The system is recognizable in the modern bottom topography where bedrock is near the surface. Where sediments are thick, minor valleys are buried beneath Recent sediments and can be detected only on continuous acoustic reflection profiles. Alder Creek, a placer-bearing creek draining into Kotzebue Sound, can be recognized on acoustic profiles, but not in the bottom topography.

Crustal model of southern Alaska Continental Shelf

D. F. Barnes and R. C. Jachens have tried to reconcile shoreline gravity measurements and marine gravity data with seismic-refraction profiling and density data from shoreline geologic mapping. Computer methods used are beginning to suggest a fairly simple crustal-model explanation:

(1) A Mohorovicic discontinuity sloping steadily downward from about 11 km deep beneath the south wall of the trench to about 35 km deep beneath the Kodiak coastline:

(2) An overlying crustal block consisting of several types of rocks, all of which have densities near 2.85 g per cu cm.

(3) An irregular wedge of light sediments beneath the continental shelf, continental slope, and trench floor. Such a simple model produces large isostatic anomalies that must be maintained by active tectonic forces.

Failure of Alaska fiord sediments

Fathometer profiles, compared with preearthquake bathymetry, and fortified by contouring of newly available extensive sounding surveys conducted by the U.S. Coast and Geodetic Survey indicate that the depression of the floor of Resurrection Bay has been as much as 70 feet according to G. A. Rusnak. Analyses of sediment samples from these same areas show that the fiord sediments are typically unstable and become "quick" when subjected to an impulsive shock such as that which occurred during the March 27, 1964, earthquake. Graded deposits are shown in X-ray radiographs of cores collected from fiord floors adjacent to delta slopes which failed. The coarse material, washed from the beach near Chenega where no delta exists, has been swept into the adjacent fiords. X-ray radiographs show the coarse material embedded at various depths in the soft fiord sediments.

Submarine topography and sedimentation in Glacier Bay, Alaska

In parts of Glacier Bay that were occupied by grounded valley glaciers less than 120 years ago, recording-fathometer studies by A. T. Ovenshine and J. G. Smith reveal 9 enclosed basins having depths ranging from 181 to 1,261 feet. The deep-water basins of Muir, Tarr, and Johns Hopkins Inlets are canoe shaped and elongate parallel to fiord axes, with bedrock sills closing basin ends. This same type of basin occurs in the broad lower part of Glacier Bay where their alinement defines two southeast-trending troughs separated by a bedrock ridge.

Marine geology of Klamath River delta

Between the Klamath River delta and Crescent City, Calif., 275 km of acoustic profiling was done under the direction of G. W. Moore. The lines averaged about 10 km apart, and numerous intersections of the lines permitted true dips to be determined. A geologic map was prepared from the survey. Additional geologic information extrapolated from land and obtained from bottom samples revealed a basement of Franciscan Formation overlain by Pliocene rocks of the St. George Formation. The St. George Formation is cut by several northwest-trending faults. Its chief structure is a series of gentle northwest-trending folds having a wavelength of about 5 km. The Pleistocene-Recent delta of the Klamath River forms a blanket as much as 60 m thick on top of the bedrock units. The results of the survey of this structurally complex area shows the value of closely spaced acoustic profiling in preparing general-purpose geologic maps of the continental shelf.

Offshore San Andreas fault system

Several hundred miles of seismic-reflection profiling was done, and about 100 bottom samples were collected by G. A. Rusnak (p. C81–C91) from the central California continental margin. The subbottom acoustical profiling has delineated offshore segments of the San Andreas fault system where the segments leave the mainland. As much as 250 feet of relative vertical movement has been recognized in strata adjacent to both sides of the main fault. The vertical displacement occurred during pre-Recent time, because no topographic relief is shown across the thinly covered bedrock. The submarine extension of the main trace of the San Andreas corresponds to its counterpart on land in that it shows little or no vertical displacement during the extensive 1906 earthquake. Apparently, little or no vertical movement has occurred on the fault during the past 5,000 years.

Structural control of Redondo Canyon

A structural trough was formed by faulting during the middle Pleistocene. At the same time, a 395-m relative uplift of the Palos Verdes Hills structural block occurred adjacent to the trough on the south. Continuous seismic-reflection profiling and mapping of the Redondo submarine canyon area revealed that the canyon had formed along this structural trough, according to R. F. Yerkes and others (p. C97–C105). Subaerial erosion of the upper part of the canyon early in the late Pleistocene is indicated by the presence of a westward-sloping channel directly inland from the canyon head. The westward-sloping channel was cut into lower Pleistocene marine deposits and then backfilled by upper Pleistocene alluvial deposits. These alluvial deposits were buried by upper Pleistocene marine deposits and younger nonmarine deposits. Down-canyon movement of longshore-drifted sediment has modified the canyon head, has kept the canyon below the level of low-sea stands, and has contributed material to the extensive submarine fan at the mouth of the canyon. The volume of the fan is at least five times that of the canyon.

OCEANIC ISLANDS

Geology of Swan Islands

Referred samples and data collected by U.S. Coast and Geodetic Survey personnel were studied by Gilbert Corwin, J. I. Tracey, Jr., Ruth Todd, Doris Low, and M. A. Smith. Five separate geologic units were distinguished by Corwin and Tracey on the Swan Islands, a small possession of the United States on the south side of the Cayman Trough in the western Caribbean Sea. The oldest unit is predominantly calcareous siltstone highly deformed along a northwestward-trending structural axis. Foraminifera from this unit were studied by Todd and Low. They determined that the beds were deposited in a deep-sea environment during Oligocene or early Miocene time. Later units are bank limestones, reef limestones, and beach deposits. Dominant fractures of the limestones strike east-west, parallel to existing regional trends of the western Caribbean.

MARINE GEOLOGIC ENVIRONMENT AND PROCESSES

Organic constituents off Florida

Jobst Hülsemann (Woods Hole Oceanographic Institution) studied the distribution and abundance of the carbonate, carbon, and nitrogen content of 50 samples from 6 core holes drilled off Jacksonville, Fla., by the Joint Oceanographic Institutions Deep Earth Sampling Program (JOIDES). The holes were drilled in 1965 on the continental shelf, upper Florida-Hatteras Slope, and the Blake Plateau. The studies indicate that two separate facies were deposited from Paleocene to Recent times. One facies has a low organic carbon and nitrogen content, a uniform carbon-nitrogen ratio, and a high carbonate content; it is characteristic of the Blake Plateau. The other facies has a higher organic carbon and nitrogen content, a carbon-nitrogen ratio that increases with age, and a relatively low carbonate content; it is typical of the continental shelf. Major changes in the abundance of organic constituents in the Eocene are believed to be due to tectonic activity rather than to changes in climate, according to Hülsemann.

Ground water from JOIDES core hole J–1

According to R. L. Wait and G. W. Leve, samples of ground water were taken from the principal artesian aquifer beneath the continental shelf at core hole J–1, 40 km east of the Florida coast. Artesian pressure caused water to flow through the drill rods onto the deck of the drilling ship *Caldrill I*. The chloride content of the samples ranged from 675 to 1,025 ppm. The pressure head measured in the unsealed hole ranged from 30 to 38 feet above the sea surface. These samples indicate that sea water is not present in the aquifer at this distance offshore, and that fresh water is discharging seaward of the areas of heavy groundwater withdrawal along the coast.

According to F. T. Manheim, the major cationic composition of the interstitial waters in core J–1 and in core J–2 (100 km east of the Florida coast) suggests that the waters are related to fresh and brackish waters found in the Floridan aquifer on the mainland. However, the waters in the cores have been in longer and more intimate contact with high magnesium-carbonate sediments, especially dolomite. Estimates of flow rates on land and comparison of water compositions suggest that fresh and brackish waters were introduced into the aquifers more than 10,000 years ago. They may have entered the cored strata during or before the Pleistocene glacial maximum, when parts of the present sea floor were exposed above sea level.

Manganese and phosphorite concretions on Blake Plateau

Manganese and phosphorite concretions occur both separately and as complex intergrowths on the Blake Plateau. The purest manganese concretions are found in water deeper than 750 m. Intergrowths and relatively pure phosphorite occur at depths of 800 m to less than 400 m according to R. M. Pratt (Woods Hole Oceanographic Institution), F. T. Manheim, and P. F. McFarlin (Woods Hole Oceanographic Institution). Unabraded fossils and erosional topography beneath the Gulf Stream suggest that the phosphorite is a lag deposit left by erosion of phosphatic sediments in coastal-plain strata. Replacement textures and relict structures and minerals indicate extensive replacement of the phosphorite by manganese minerals, mainly todorokite. Both concretionary and replacement manganese nodules have a high iron content, partly in the form of goethite. Petrographic and field relations show that the manganese concretions are younger than the phosphorite and are accumulating under present-day environmental conditions. Fragments of manganese crusts in phosphate-cemented aggregates indicate that the manganese and phosphate have been involved in several episodes of reworking and re-solution. Carbon-14 dating of manganese-encrusted coral suggests rates of manganese deposition on the order of 0.01 mm per 1,000 years according to Pratt, Manheim, and McFarlin.

Volcanic processes in offshore Hawaii region

J. G. Moore and R. S. Fiske participated in an oceanographic study of volcanic processes on the submerged flanks of Mauna Loa and Kilauea volcanoes. The cruise was part of a cooperative program of the U.S. Coast and Geodetic Survey, Environmental Sciences Services Administration, and the U.S. Geological Survey. More than 4,000 photographs of the ocean floor were obtained from 17 camera stations. Preliminary studies of the photographs show a predominance of pillow lavas on the submarine rift zones of the volcanoes. Vast quantities of fresh glass sand mantle the submarine south flank of Kilauea volcano. The glass sand is thought to be formed by explosive disintegration of land-based lava flows when the hot flows enter the sea.

East cape of island of Hawaii mapped

The ocean bottom topography of a 100-square-mile area off the east cape of the island of Hawaii was mapped by echo sounding according to J. G. Moore. The mapped area includes a part of the east rift zone of Kilauea volcano. The mapping showed a trench directly on line with the rift zone on land. The trench ranged from ½ to 1 mile in width, was several hundred feet deep, and is thought to be an extension of the Kapoho graben, a trench bounded by faults located on the east cape and extending into the sea. The graben has subsided twice in historic time (1924 and 1960) apparently by collapse of the surface due to withdrawal of support as magma moved through the rift zone, perhaps to erupt downrift in submarine volcanic activity.

Analysis of contoured magnetic data over the oceanic extension of the east rift zone of Hawaii indicated that the large 2,000- to 3,000-gamma associated magnetic anomaly is caused by topography, according to Andrew Griscom in a study done in cooperation with the U.S. Geological Survey–U.S. Coast and Geodetic Survey oceanographic program off Hawaii. Smaller linear anomalies trend parallel to the ridge crest and may be caused by intrusions that fed the flows.

ESTUARINE HYDROLOGY

Salt-water intrusion in Duwamish River estuary, Washington

Two dye studies of surface-dispersion characteristics made during low fresh-water discharge (less than 350 cfs) indicate that more than 90 percent of a surface pollutant will be flushed out of the estuary in less than 5 days. According to J. F. Santos, the studies were made using two sampling techniques. Sampling was done either from a single point near the mouth of the estuary or where top and bottom samples were collected longitudinally throughout the estuary. The single-point sampling technique produced good results for flushing rates, the longitudinal sampling gave valuable information on the mixing characteristics. Data from the longitudinal study suggested that the fresh-water surface layer did not migrate into the salt wedge in the estuary proper. Instead, after most of the dye-tagged fresh water had been flushed out of the estuary, it mixed with the salt water off the mouth of the estuary and returned in the salt wedge.

An accurate prediction method for salt-water intrusion at a primary station on the Duwamish River has been developed by J. D. Stoner (p. D253–D255). For a fresh-water discharge of less than 625 cfs, salt-water intrusion occurs regardless of the high-tide height, whereas a discharge greater than 1,000 cfs prevents intrusion at any tide stage. For a fresh-water discharge between 625 and 1,000 cfs, intrusion is dependent both on discharge and high-tide height.

Tidal flow, Hudson River estuary, New York

Preliminary analysis of the tidal-flow data revealed large flows of water in each tidal cycle. M. W. Busby reported that maximum discharges of 300,000 to 400,000 cfs are not uncommon for both ebb and flood tides. Volumes of flow for individual tides were as large as 8 billion cu ft. Daily total volumes were as large as 20 billion cu ft. Net upstream flows (flood-tide volumes larger than ebb-tide volumes) were observed to occur for as many as 4 to 5 consecutive days. The salt-water front was observed moving rapidly upstream during these periods.

Tidal observations, Raritan River estuary, New Jersey

The vertical-velocity curves of the tidal flow varied from near normal at the higher velocities to flow in one direction at the surface and in the opposite direction near the bottom near time of slack tide, acccording to A. C. Lendo. The latter curves were smooth and did not show an abrupt break which would result if there was a wedge. Vertical-salinity profiles indicate a nonhomogeneous mixture, although not of the wedge type. The water of the Raritan River was highly saline. The river cross sections contracted considerably in the upstream direction.

Water quality, Patuxent River estuary, Maryland

R. L. Cory and J. W. Nauman observed that maximum summer surface-water temperatures in the unpolluted estuary were no higher than in previous years (30.5°C), but at a station 1,000 feet from the powerplant discharge, the temperature was 34.6°C (94.3°F). Heated surface water was detected 4½ miles from the discharge point where temperature was elevated 1°C above normal. Salinity from June through September reflected drought conditions. A September high of 14.2 percent was reached as compared to a previous high of 13.0 percent for the same month.

Percentage saturation of oxygen was highest, 145 percent, in October, indicating a large plankton bloom. The largest set of barnacles, *Balanus improvisus*, during this study was recorded in November. A significant set continued through the month of December, a month when none had previously been recorded. It is believed that runoff from September and October rains flushed nutrients into the estuary and triggered the plankton bloom. This together with water at temperatures above 12°C in November and 9°C in December created a favorable environment for the barnacles. It is known that spawning activity of barnacles is induced by food availability and favorable temperatures.

Epifauna of Patuxent River estuary

The season of attachment and production of biomass of the epifauna were noted by R. L. Cory and J. W. Nauman to vary greatly at 9 locations during a 4-year period. The numbers of species and community composition remained stable and predictable, though wide variations in numbers of individuals occurred. Effects from addition of powerplant cooling water in the estuary were generally slight at a station 1,000 feet from the discharge point, although noticeable reduction in numbers of species was noted during June and July. Additional observations showed a complete mortality of the epifauna within the confines of the mile-long effluent canal. This mortality coincided with the death of thousands of the commercial crab *Callinectes sapidus*. Biomass production increased during spring and autumn at the station influenced by the heated water. Additional heat apparently favors the growth of these organisms.

SUBSEA MINERAL RESOURCES

Distribution and factors affecting localization

As an aid to subsea prospecting for mineral resources, K. O. Emery (Woods Hole Oceanographic Institution),[69] and V. E. McKelvey and Livingston Chase (r0309) summarized their distribution and the factors controlling their localization. The chief subsea mineral resource now and probably in the future is petroleum, produced currently only from the continental shelves but with an unexplored potential also beneath the continental slopes and deep ocean floor. Other mineral resources that have been recovered commercially include sand, gravel, shell, lime mud, diamond, cassiterite, and other heavy-mineral concentrates. Deposits of phosphorite are extensive in some areas of upwelling on the continental shelves and have some potential in regions in which other sources are remote. Manganese nodules are extensive in many parts of the deep ocean floor but pose difficult recovery problems.

The continental shelves are not only most accessible to exploration and mining but also contain most of the presently valuable mineral deposits. Some favorable areas within them can be defined from present oceanographic and geologic knowledge.

Heavy metals in the marine environment

Analyses by atomic absorption for detrital gold in more than 2,000 samples of beach, marine terrace, and offshore sands have shown that the values determined from raw or unconcentrated sediment are neither reproducible nor representative of the initial sample. The difficulty results from the random flake effect, whereby the analysis for gold in a given sample depends more upon the occurrence of random flakes of gold in the analyzed portion than upon the actual gold content of the sample, according to H. E. Clifton and others [70].

The random flake effect can be eliminated mostly by concentrating all of the gold in a sample into an analyzable portion before submittal to the analyst. A combination of sieve, gravimetric, and magnetic separation produces a satisfactory concentrate yielding accurate and reproducible analyses. Analysis of concentrates provides a means of greatly increasing the sensitivity

[69] K. O. Emery, 1966, Geological methods for locating mineral deposits on the ocean floor: Marine Technology Soc., Trans. 2d Ann. Conf., p. 24–43.

[70] H. E. Clifton, Arthur Hubert, and R. L. Phillips, in press, Marine sediment sample preparation for analysis for low concentration of fine detrital gold: U.S. Geol. Survey Circular 545. [Published Aug. 1967]

of the analytical technique used on the initial sample. A minimum amount of raw sample is required to provide an analyzable portion containing detectable gold. The amount differs, depending on the lithology, but as a rule, a minimum of 300 g of marine sediment is needed in order to provide a reasonable chance of producing a concentrate that will yield a positive analysis for gold.

ASTROGEOLOGY

EARTH-BASED LUNAR INVESTIGATIONS

Before mapping was begun on Lunar Orbiter photographs, lunar investigations had been based on geologic mapping of the Moon from telescopic data at scales of 1:1,000,000 and 1:500,000. Figure 6 summarizes the status of this mapping.

Structure of northern periphery of Mare Imbrium basin

Five preliminary maps completed in 1966 cover the northern half of the Mare Imbrium basin and its peripheral structures in the northwest part of the Moon. This region lies at a comparable distance from the center of the Imbrium basin to those regions where lunar stratigraphic units were first recognized and where most of the previous years' mapping efforts were concentrated. Most of the mappers working on the northern region recognize hummocky terrain similar to that mapped as Fra Mauro Formation in the areas to the south but find evidence that the morphology of much of this northern terrain is structural as well as depositional in origin. There are fewer structures of the Imbrian radial system (Imbrian sculpture) in the north than in the south. The Cassini quadrangle covers a low area between the Montes Caucasus and the Montes Alpes that is critical for determining the relation between the major southern and northern peripheral structures concentric to the Imbrium basin. Some previous workers believed that the Caucasus and Alpes are part of the same structure that has been offset by a northeast-trending left-lateral strike-slip fault in the

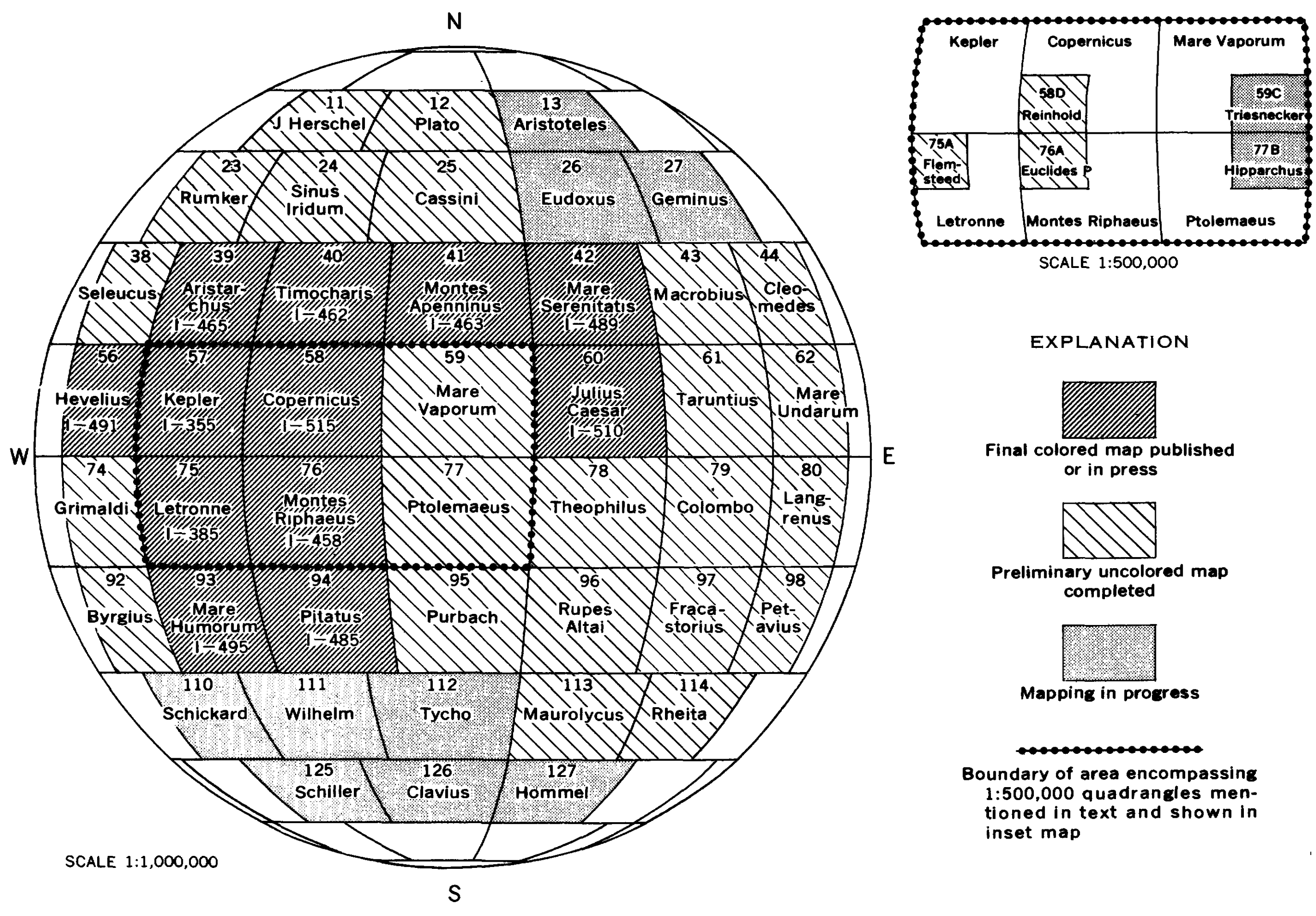

FIGURE 6.—Index map of the Moon, showing status of geologic mapping at a scale of 1:500,000 and 1:1,000,000. ACIC (Aeronautical Chart Information Center) number and name are given in each region. I– numbers identify maps in the U.S. Geological Survey Miscellaneous Geologic Investigations series.

gap. N. J Page shows that this is unlikely because structures in the gap are mostly normal faults. The Alpes probably represent the same structure as the rugged terra on the south side of Archimedes, and the gap represents a continuation of the low shelf that lies between this rugged terra and the Montes Apenninus.

Comparison of lunar rilles and terrestrial graben

G. I. Smith has found that the lunar rilles Rima Ariadaeus and Rimae Hypatia I and II and two young graben in southeast California have several characteristics in common. The walls of the lunar rilles probably are fault scarps—as are the walls of the terrestrial graben studied. Facing scarps of both rilles and graben are sinuous in detail but straight in overall trend, and tend to be equidistant and parallel throughout their length. The boundary faults are not continuous single fractures but a series of nearly alined, overlapping en echelon fractures. The absolute dimensions and proportions of the rilles and graben are different, but their width-to-depth ratios are similar. The lunar rilles appear to be graben and thus would have been produced by an extension of the crust, though the fundamental cause of the extension may be different from that on Earth. They are probably tectonic; thus, moonquakes may have accompanied their formation. Moreover, because the lunar graben vary in age, extent, and orientation, the lunar stress-and-strain fields have apparently migrated, implying a mobile subcrustal zone.

Structure of Triesnecker-Hipparchus region

In a detailed study of linear structures in the Triesnecker-Hipparchus region near the center of the Moon's disk, T. W. Offield has defined and interpreted probable relations of the structures to mare basins, to a possible lunar structural grid pattern, and to other regional structures. Many structures that are radial and concentric to the Imbrium basin and radial to the Serenitatis basin are present. Other structures appear to be radial to the Tranquillitatis and Nectaris basins. Genetic relation of individual structural features to the various basins is implied by the geometric relations, although the relationship cannot be proved in this restricted area. Many remaining structures are partly related to a lunar structural grid pattern recognized by earlier workers, but the peak azimuths plotted on rose diagrams differ in this area from those of the grid. Detailed examination of the possible lunar grid structures shows that earlier explanations involving Moonwide stresses are not satisfactory. Two other strong systems that may not be part of a Moonwide grid trend north to 15° E. and within 15° of east. These two systems are relatively young and may result from relatively late regional tension that differed from earlier stresses; they may be independent of any Moonwide stresses. This study, like the preceding study by G. I. Smith, supports the conclusion that lunar stress-and-strain fields have migrated in time.

Young mare materials

In early lunar geologic work most of the materials of the lunar mare surfaces were thought to be approximately of the same age and were mapped first as the Procellarian System and later as the Procellarum Group of the Imbrian System. However, as mapping progressed, differences in age became evident, placing doubt on the hypothesis of a single episode of mare formation. Previous mapping has shown the existence of old marelike units among light plains-forming materials and of young dark mare material in areas of generally older and lighter mare material. As examples, two occurrences of mare have been identified as relatively young by the fact that the mare material embays young craters; the crater rim material is superposed on mare in one sector and overlapped by it in another. One such young crater embayed by still younger mare material is Lichtenberg, a bright-rayed crater of definite Copernican age in the Seleucus quadrangle, mapped by H. J. Moore. The young mare material near Lichtenberg is located along part of a lineament that extends for at least 1,000 km, and the mare material may have been extruded from fissures along the lineament. Another mare-embayed crater, mapped by D. E. Wilhelms, is Manilius, of either Eratosthenian or Copernican age and located on the boundary between the Mare Vaporum and Julius Caecar quadrangles. The mare material that embays Lichtenberg and Manilius is dark, supporting the tentative hypothesis that the darkest mare surface materials are the youngest. Other dark mare materials that resemble these may also be younger than the Procellarum Group, but definite criteria for dating them are lacking. Most of these dark mare materials, as well as most young non-mare volcanic materials, are at the margins of basins, suggesting that the marginal areas are among the most recently active lunar volcanic zones.

Young dark mantling deposits

Many tracts of lunar terrain, both rugged and flat, have a fairly uniform low albedo—as low or lower than most of the maria. The topographic differences probably are the expression of different materials; the low albedo probably results from a thin mantle of younger material. This mantling material is probably volcanic and chiefly pyroclastic. The first such mantling unit recognized was the Sulpicius Gallus Formation, mapped and named by M. H. Carr in the Mare Serenitatis quadrangle. It has recently been identified in an area covering thousands of square kilometers in the Copernicus and Mare Vaporum quadrangles. Some of the Sulpicius Gallus Formation is older than the mare material and some is younger. Some young patches of probable Sulpicius Gallus contain very dark spots which are probably dark-halo craters, like those in the crater Alphonsus photographed by Ranger IX, and these craters may be the source of the material. Two other dark mantling units are the Doppelmayer Formation at the margins of the Mare Humorum basin, mapped by S. R. Titley, and the Cavalerius Formation in the Hevelius quadrangle at the edge of Oceanus Procellarum, mapped by J. F. McCauley. The Doppelmayer may be approximately the same age as the Sulpicius Gallus, but the Cavalerius is younger and covers bright ray materials from craters of Copernican age. The Cavalerius Formation is the unit on which the Soviet soft-landing spacecraft Luna 9 probably landed. Other dark mantling materials cover much of the Aristarchus plateau in the northwest quadrant of the Moon near the crater Aristarchus and have been mapped by H. J. Moore as part of the Vallis Schröteri Formation, which is probably younger than the nearby mare material. Domes and cratered cones that resemble volcanoes, craters unlike typical impact craters, and sinuous rilles, which may partly be flow channels, are also found in the Aristarchus area, suggesting that it has been the site of long-continued volcanism. Other smaller dark areas of rugged topography are being mapped from recent superior full-moon photographs in nearly every part of the Moon, and it appears that these relatively recent dark mantling deposits of pyroclastic material are widespread on the Moon. They are commonly located at the margins of mare basins and large craters, as are the dark mare materials and other probable volcanic materials.

Interpretation of thermal anomalies at eclipse

The magnitude of thermal anomalies of certain lunar craters at eclipse has been measured by workers at Boeing Scientific Research Laboratories and shown on recently refined contour maps. The anomalies have been found to correlate fairly well with age criteria developed previously by the Geological Survey. Most high anomalies occur on craters with either bright rays or dark halos that had been assigned to the Copernican System largely on the basis of stratigraphic and morphologic criteria. Most low anomalies occur on craters that have medium-albedo rim material and no discrete rays or only very faint rays, and so had previously been designated Eratosthenian. This apparent correlation may be explained by the fact that fresh, solid rock has a higher thermal conductivity than fragmented rock. The solid bedrock exposed at the surface of fresh craters is in good thermal contact with the underlying materials, thus allowing a rapid transfer of the heat stored below the surface. Consequently a high surface temperature is recorded during eclipse. In older craters, where the bedrock is covered by an insulating layer of fragmental material, the transfer of heat to the surface is much slower, and a lower surface temperature is recorded. The apparent correlation is an aid in geologic mapping since it can be used to date craters of otherwise indeterminate age, such as those having bright rim material but no detectable discrete rays. Light-rimmed craters on terra commonly have low anomalies, whereas craters having rims with moderate albedo on mare commonly have high anomalies. This relationship suggests that source material has an effect on the albedo of rim material. Several elongate and irregular craters that are of probable volcanic origin have high anomalies. Presumably they are young, although previously no criteria had been established to determine their age. Fresh solid rock is probably exposed in these craters as well as in the impact craters.

STUDIES OF IMAGES RECEIVED FROM SPACECRAFT

Geologic maps being prepared from Ranger photographs

Photographs returned by Rangers VII, VIII, and IX are being used to prepare lunar geologic terrain maps at scales as large as 1:50,000. Preparation of these maps has been helpful in making the transition in scale from earth-based observations to the scale of Lunar Orbiter photographs. Variations in the areal density of craters and in details of surface texture shown by these photographs are the basis for division of plains-forming terra and mare materials into several units.

During 1:500,000-scale geologic mapping from Ranger VII photographs, R. E. Eggleton found evidence for the sequence of formation of individual craters within a local cluster of what seem to be secondary impact craters around the crater Bullialdus. A string of craters within the cluster includes three composite craters each of which is apparently a pair of circular craters resulting from two principal impacts. In two pairs, the crater farther from Bullialdus has a sharper crest and steeper slopes than the nearer. This suggests that in both pairs the farther crater was formed later so that its ejecta was superimposed on the nearer crater.

N. J. Trask has classified the craters photographed by the Ranger VIII and IX spacecraft into four categories according to relative sharpness. Craters 100 m or more in diameter have broad rims and low depth- to-diameter ratios and are partly covered with smaller craters which generally have sharper rims and higher depth- to-diameter ratios but include all morphologic classes. A higher proportion of sharp craters in the smaller sizes suggests that a smooth surface, produced by an episode of intense crater destruction, has been subsequently recratered.

Preliminary analysis of Lunar Orbiter photographs

Lunar Orbiters I and II photographed nearly 500,000 square miles of the near side of the Moon and about 7,000,000 square miles (about 50 percent) of the far side. The primary objective of these missions was to obtain topographic and geologic information at 9 primary Mission I and 13 primary Mission II sites to test their suitability for Apollo and Surveyor landings. Numerous secondary sites on both sides were also selected to provide geologic information. Resolutions as great as 1 m on the near side and 250 m on the far side were obtained. Lunar terrain analysis and geologic mapping by the Geological Survey aided in selection and documentation of the sites.

Preliminary analysis of the 22 primary sites based on geologic terrain maps at scales of 1:100,000 and 1:10,000 and crater size-frequency data shows a great variation in surface roughness. Nine primary sites appear to contain areas that meet the present topographic and geologic constraints and operational preferences of Apollo.

Although geologic analysis of Orbiter photographs is still in the initial stages, several significant observations can be made which have influenced the objectives of current investigations.

L. C. Rowan has found that the area covered by craters on the maria ranges from saturation in rayed areas to as little as 6 percent in a few small areas outside rays. Deficiencies occur in the 75- to 200-m-diameter crater range in these smooth areas and on terra slopes. These observations suggest that craters have been obscured or destroyed on some mare and terra surfaces. A combination of impact, volcanic, and mass-wasting processes is probably required to explain these observations.

Ledges or terraces occur in the walls of many well-formed craters shown in Lunar Orbiter photographs. In view of the results of cratering experiments, this suggests that a layer of fragmental material overlies the mare bedrock. Through analysis of the depth of occurrence of these terraces and by statistical analysis of crater morphologies, R. E. Eggleton and H. J. Moore have independently developed techniques for determining the thickness of this unconsolidated material. M. J. Grolier reports that a terrace occurs at a depth of about 10 m in the Ranger VIII impact crater, which may mean that the fragmental layer is, at least locally, 10 m thick. The thickness probably ranges from 2 to 10 m over the maria. Grolier located the Ranger VIII impact crater by image matching Lunar Orbiter II and Ranger VIII photography and by using Ranger VIII trajectory data.

Lunar Orbiter II has provided an excellent basis for evaluating the size-frequency distribution of protuberances on the mare, because many different geologic settings have been photographed at high resolution (1 m). Blocks larger than 1 m in diameter cover only a small percentage of typical mare surfaces and are concentrated around bright-rayed well-formed craters and in the walls and rim deposits of moderately subdued craters. Blocks as large as 80 m in diameter occur around large craters and along escarpments, but on typical mare surfaces most blocks are less than 12 m in diameter.

Two of the most striking features observed in Lunar Orbiter photographs are the frequent occurrence of patterned ground on most slopes and some apparent plains and of terraces at the contact of sloping surfaces and nearly horizontal plains. The patterned ground consists of alternating ridges and depressions which are a few meters in wavelength and occur on both the mare and the terra. The trend of the ridges and depressions is apparently controlled by topography where parallel to topographic contours. In some areas, however, planar features in the bedrock are apparently the primary influence.

Terraces as much as 300 m wide and 30 m high occur most commonly at the break in slope along the contact of the mare and terra, but similar terraces have also been observed at the base of crater walls and on terra. L. C. Rowan notes that the detailed morphology, crater size-frequency distribution data, and stratigraphic relations suggest that these terraces were formed by the downslope movement of fragmental material. T. N. V. Karlstrom suggests that differential compaction of mare material may also play an important role. S. R.

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Titley has studied crater forms and surface texture and concluded that modification by slumping, creep, and differential compaction has occurred and that combined impact seismicity and endogenous seismicity could start downslope movement.

Surveyor television investigations

The Surveyor television cameras have recorded detail on the lunar surface as fine as 0.5 mm. This represents a gain of at least three orders of magnitude over the highest resolution obtained by the Ranger and Lunar Orbiter pictures.

The surface on which Surveyor I landed is composed of poorly sorted fragmental material ranging in size from large blocks to smaller fragments set in a matrix of fine particles. The interaction of the spacecraft footpad with the surface and the shapes of small natural craters show that the upper few centimeters of surface material has some cohesion but probably less than 10^5 dynes per cm^2. The average depth of the smallest craters from which strongly cohesive material has been ejected is about 1 m.

The size-frequency distribution of craters in the near field of the spacecraft follows the power function

$$N_d = 6.5 \times 10^5 d^{-1.80},$$

where N_d = cumulative number of craters per 100 sq. m, d = diameter of crater in mm, and $16 \leqq d \leqq 400$.

The size-frequency distribution of angular fragments is

$$N_y = 3.0 \times 10^5{}_y{}^{-1.77},$$

where N_y = cumulative number of angular fragments per 100 sq m, y = diameter of grains in mm, and $1 \leqq y \leqq 100$.

The observed angular fragments occupy 7.6 percent of the surface area and have a volumetric median grain size of 130 mm. The volumetric median grain size of all fragmental material on the surface may be of the order of 1 mm.

About one crater 6 m in diameter or larger and one block 1 m across or larger are found on each 100 sq m of the lunar surface around Surveyor I.

STUDIES RELATED TO MANNED LUNAR EXPLORATION

The U.S. Geological Survey's manned lunar exploration studies include geologic training of the astronauts, geologic mapping and geophysical studies on sites suitable for tests and simulations of early Apollo and post-Apollo types of lunar missions, and supporting research in terrestrial and lunar geology and geophysics.

Astronaut training

The Geological Survey in cooperation with geologists at the Manned Spacecraft Center of the National Aeronautics and Space Administration continued the program to train astronauts in geology. The purpose of the program is to teach the astronauts to carry out geologic studies on Apollo missions.

The course of training in geology offered to the first three groups of astronauts included a lecture series and field exercises. A similar course of training, extending over a 2-year period, was begun for a fourth group that includes 6 scientist astronauts and 19 pilot astronauts.

Lectures, conducted by A. C. Waters and A. H. Chidester, were of an introductory nature covering the principles of terrestrial and lunar geology. Field exercises included trips to the Grand Canyon (E. D. McKee, leader); Marathon Basin – Big Bend area, in west Texas (W. R. Muehlberger, leader); Newberry Volcanic Crater near Bend, Oreg. (A. C. Waters, leader); Valles Caldera in northern New Mexico (R. L. Smith, leader); Katmai Volcanic Field, Alaska (R. L. Smith, leader); and Pinacates Volcanic Field, Sonora, Mexico (R. H. Jahns, leader).

Early Apollo investigations

Geologic investigations to be conducted on Apollo lunar missions appear to be restricted to the detailed investigation, on foot, of a few selected lunar features. Field tests, using geologists as test subjects, show of course that the traversing of terrain and the performance of geologic tasks is slowed considerably when a space suit is worn. However, techniques such as automatic tracking, data handling, and analysis, as well as map compilation by a monitoring team, should largely offset the time restrictions imposed by working in a space suit and should permit fieldwork in limited areas to be accomplished as rapidly and as accurately as by a geologist working in shirtsleeves.

Tests run under conditions of one-sixth gravity indicate that astronauts in a space suit should be able to use geologic equipment designed for the early Apollo landings with no great difficulty. The equipment includes a three-legged carrier for tools and samples, rock hammer, a sample scoop, a long-handled sample grabber, drive-core tubes, hand lens, brush, scriber, a single-lens camera, gnomon (plumb penulum on tripod), surveying instrument, and hand-held staff to which the camera and surveying instrument may be affixed. Both Geological Survey personnel and personnel of the Manned Spacecraft Center are jointly responsible for the establishment of design specifications and laboratory and field testing of prototype equipment.

Tests indicate that the coordination and correlation of geologic information delivered to earth during an Apollo mission apparently can best be handled by a panel of scientists working through a coordinator-communicator with the astronauts. Each scientist would be responsible for the analysis of a specific part of the geologic data being returned and also serve as an advisor to the mission-coordinator and astronauts. Each panel member would have a supporting team which will be responsible for data manipulation and display of that data. A general computerized display program will allow any panel member to recall and display geologic data in a number of different forms (for example, to recall a list of specimens having a number of similar attributes or to recall data conflicting with a particular geologic model or hypothesis under investigation).

Post-Apollo investigations

The objective of lunar geologic exploration during post-Apollo landings will be to gather, compile, and interpret all possible data pertinent to defining the geologic processes that have occurred on the surface and in the interior of the Moon. Astronauts will be greatly facilitated by an Astrogeologic Data Facility (ADF) designed to compile, correlate, and display the geologic data transmitted to it by the astronaut. During the field exercises conducted for the purpose of developing techniques and equipment for geologic exploration during lunar missions, a team working in a data facility has been able to monitor and record the test subjects' observations to insure completeness, clarity, and accuracy. They aid in pacing the subjects' progress on the traverses, thereby accomplishing the planned objectives of the traverse. With the aid of their compilations, the team is able to offer interpretations not readily apparent to the man in the field.

REMOTE-SENSING STUDIES

The U.S. Geological Survey continued its cooperative program on remote-sensing investigations with the National Aeronautics and Space Administration to (1) determine what aspects of natural-resources study might be best observed by airborne and spaceborne remote sensors; (2) select, for spaceflight experimentation, those instruments that might provide the most meaningful data toward solving resource problems; and (3) develop a cadre of earth scientists experienced in the application and interpretation of remote-sensor data acquired from aircraft and spacecraft.

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS

Investigations during the year included theoretical, laboratory, and field investigations using ultraviolet and infrared instruments and empirical studies of imagery and photography by field geologists. The empirical studies were based, for the most part, on infrared and radar data acquired from aircraft. Studies of space-acquired data were based upon Gemini color photography and Nimbus vidicon photography and high-resolution infrared (HRIR) imagery.

PHOTOGRAPHIC STUDIES

Gemini color photography

Gemini color photographs that were studied and annotated include the Salton Sea, Calif., area, by E. W. Wolfe; the Salt Range–Potwar Plateau region, West Pakistan, by W. R. Hemphill and Walter Danilchik; the Duba area, Saudi Arabia, by R. F. Johnson and J. A. MacKallor; a series extending from the Gulf of California eastward to El Paso, Tex., by Harald Drewes and Roger Morrison; and five photographs of the fringes of the Sahara desert in Africa by J. R. Jones.

These studies showed that the small-scale synoptic views are highly useful in evaluating large areas and that many geographic, cultural, hydrologic, and geologic features could be identified with ease. Color rendition of soils and rock materials is best in desert areas, where atmospheric interference was least. Surficial geology, volcanic features, major faults, folds, and fractures, soil, water and vegetation distribution, grazing and cultivated areas are a few of the features that can be recognized.

Nimbus-imagery evaluation

Nimbus satellite vidicon photography and infrared imagery, primarily intended for weather information, were analyzed by several investigators. D. C. Hahl and A. H. Handy found that the shape of Great Salt Lake, Utah, shown by Nimbus vidicon images is markedly different from that shown on maps and recent aerial photographs. Several features, known to be covered with shallow water, appear as land areas. The open-pit copper mine at Bingham, Utah, is visible on the photograph.

C. R. Lewis and W. E. Davies, in evaluating a Nimbus vidicon photograph of the Chesapeake Bay and Blue Ridge areas of the eastern United States, found that the Coastal Plain, Piedmont, Blue Ridge, and

Triassic fault blocks can be identified, but that only gross geologic features and very few cultural features can be recognized.

W. E. Davies also studied a Nimbus vidicon photograph of northwest Greenland. He found that sharp distinction can be made between exposed land and snow- or ice-covered areas. Some ice-covered areas are inferred to be structurally controlled, because of their linearity.

Data-interpretation techniques by color mimicry

B. F. Grossling found that a composite picture of the same scene can be made from conventional black-and-white aerial photography, infrared photography, and infrared imagery. Different colors were used to represent the frequency information and other positional parameters in each of the images. Although this preliminary experiment was successful in showing the advantages of using color-mimicry techniques to represent parts of the electromagnetic spectrum, it also pointed to the difficulty in handling images of different geometry. A principal difficulty arises from the differences between perspective aerial photography and the line scan images from infrared and radar systems. Wide scan infrared images also differ markedly in geometry from side looking radar (SLAR) images.

Airborne multispectral television system

Multispectral television images in the visible and near-infrared ($<2.2\mu$) region of the spectrum were recorded on videotape in a light aircraft by C. J. Robinove and H. E. Skibitzke (p. D143–D146). The images are of lower spatial resolution than aerial photographs from equivalent altitudes but have the advantages of allowing narrow bandpass filtering and instant reproduction of the images for use by interpreters. Such imagery may be quite useful for fast coverage of dynamic events, such as floods, where aerial data are needed quickly but the photogrammetric precision of aerial photographs is not necessary. The use of airborne television imagery by field scientists also will prepare them to use similar but smaller scale data from earth-orbiting satellites.

INFRARED STUDIES

Coal-mine-fire extent determined

R. M. Moxham conducted aerial surveys with a line-scanning infrared radiometer over a serious coal-mine fire in and under the Cedar Avenue area of Scranton, Pa., where carbon monoxide gas seeping from burning culm banks and underground workings necessitated evacuation of the area. The aerial surveys proved useful in determining the extent of the fire area and were used by the U.S. Bureau of Mines in planning control measures, including excavation for a fire-perimeter barrier.

Heat transfer of Taal Volcano, Philippine Islands

A series of six infrared surveys by R. M. Moxham and Arturo Alcaraz (Philippine Commission on Volcanology) over Taal Volcano, Philippines, beginning shortly after the 1965 eruption and continuing through the 1966 eruption, indicate that changes in the convective heat-transfer system took place during the survey period and that such changes can be documented by infrared surveys. The heat transfer is mainly by hot springs whose location is inferred to be controlled by pre-1965 faults, which in turn exercised some control over the location and configuration of the 1965 and 1966 eruption craters.

Distribution of soil moisture

R. E. Wallace and R. M. Moxham found infrared imagery useful in showing the distribution of soil moisture associated with landslide features along the San Andreas fault zone, in the Carrizo Plains area, California.

Thermal emission of Surtsey and other Icelandic volcanoes

J. D. Friedman, in cooperation with R. S. Williams, Jr., of the Air Force Cambridge Research Laboratories, and Gudmundur Pálmason, of the National Energy Authority of Iceland, conducted ground and aerial infrared investigations of erupting Surtsey volcano (August 1966) and several other volcanic areas and geothermal power sources in Iceland. Icelandic ground observations at Surtsey of volumetric yield (7 m^3 per sec) of basaltic lava at 1153°C permitted calculation of the rate of thermal-energy release (2.7×10^{17} ergs per sec). Airborne infrared imagery and ground-temperature data gave the distribution of anomalously warm surfaces of different temperature levels, leading to an estimate of the radiance and the equivalent black-body temperature (302°–329°K) that would be recorded by the Nimbus II HRIR (high-resolution infrared) system as the apparent integrated temperature of Surtsey volcano and surrounding ocean surface. Later, Williams and Friedman detected a thermal anomaly representing Surtsey on seven orbital swaths of Nimbus II HRIR imagery, recorded in part concurrently with airborne and ground observations; the radiance value ($10^{-0.75}$ w/m^2 steradian or equivalent black-body temperature of 308°–312°K) for the Surtsey anomaly recorded on the Nimbus II scan-line analog profiles confirmed the radiance estimates based on ground observations.

Airborne infrared imagery also indicated considerable thermal emission from three other volcanos in

Iceland: Askja, Kverkfjoll, and Hekla. On the Reykjanes peninsula the alinement of high-temperature thermal areas along structural lineaments and the location of a sublacustrine thermal spring in the lake Kleifarvatn were confirmed. New surface manifestations of thermal activity were detected north and east of the lake Myvatn in northern Iceland.

Thermal emission from hot springs and fumeroles, Mono Lake, Calif., area

J. D. Friedman and S. J. Gawarecki found that several hot springs and fumaroles around the periphery of a Quaternary andesitic volcano on Paoha Island in Mono Lake, Calif., are controlled by faults transecting the crater remnant. Relative intensity of thermal emission from the hot springs and fumaroles was mapped by airborne infrared imagery and isodensitracer scanning techniques. On the basis of temperature and rates-of-flow measurements the total thermal-energy release may be greater than 18×10^6 cal per sec.

Rock-type-differentiation studies

Field observation of diurnal surface-temperature variations of dry natural surfaces in the Mono Lake area of California by J. D. Friedman and S. J. Gawarecki concurrently with sequential infrared-imagery surveys at 4-hour intervals throughout a 24-hour cycle, indicates that the time-rate of change of infrared emission is controlled by the total reflectivity, thermal inertia, and apparent emissivity of the surface as well as by the incident radiant flux. Dry pumiceous ash-fall tephra of low bulk density was found to have a particularly high-amplitude diurnal surface-temperature curve and could be distinguished on infrared imagery where it is in contact with higher density flows or bedrock. Textural differences in rhyolite obsidian flows, not distinguishable on aerial photographs, were detected on the infrared imagery by application of this method.

New Mexico surveys

S. J. Gawarecki reports that infrared surveys were conducted in the areas of Twin Buttes, Ariz., the Tyrone and Santa Rita copper districts of New Mexico, and of a "hot ground" area southwest of Lordsburg, N. Mex., using an 8–14μ infrared scanner. A thermal anomaly near Lordsburg was delineated and closely matches a geothermal map of the area.

Subaqueous fault-controlled springs identified in Yellowstone Lake

Several alined cold springs discharging onto the floor of Yellowstone Lake have been detected by H. W. Smedes during a study of infrared images of Yellowstone Park. The springs issue near Dot Island at depths of more than 100 feet. Where the spring water reaches the lake surface it makes a dark tone on the infrared image which contrasts sharply with the light tone of the surrounding normal lake water. This sharp contrast suggests that there is little dilution and warming of the spring water during ascent to the surface. This, and the fact that the cold water ascends 100 feet or more through warmer water, indicates that the springs probably have rapid flow and large volume.

The line of springs is subparallel with a prominent scarp of the lake floor, whose west side is more than 100 feet higher than the east. The springs also lie along the northern projection of a conspicuous topographic scarp and major fault (west side up) mapped to the south by earlier workers. The outlets of these springs are interpreted as being at intersections of an extension of the known fault and fractures of east or northeast trend.

Thermal anomaly in Millers River, Mass.

In a study of the applications of infrared imagery to hydrologic problems, D. R. Wiesnet found a thermal anomaly in the Millers River near Orange, Mass., which was attributed to ground-water seepage. The river cuts into a glacial-outwash aquifer which is large in size but composed mainly of fine-grained material. The estimated ground-water outflows along the affected reach of riverbank is approximately 2 million gallons a day.

Thermal state of Merrimack River estuary

Infrared imagery of the Merrimack River estuary was used to study the thermal state of the estuary at high, low, flood, and ebb tides. The imagery delineates the salt-water front at high and flood tides because of the marked difference in sea (warm) and river (cool) surface temperature. From the imagery, D. R. Wiesnet and J. E. Cotton have also inferred details of circulation not previously known. Data on water temperature, salinity, tide levels, meteorology, radiometry, air temperature, and humidity were gathered to support their interpretations.

Detection of submarine springs

The location of submarine springs and dispersed ground-water discharge along the seashore could have practical value in identifying shoreward areas where water wells might be drilled. The difficulty and expense of direct observation is prohibitive, and remote-sensing tools are being investigated by F. A. Kohout for application to the problem. Submarine springs 12 miles offshore from Naples, Fla., and 2½ miles offshore from Crescent Beach, Fla., were recognized with varying degrees of success by color photography, multispectral photography, and infrared imagery. The success of infrared imagery depends on the temperature contrast between the discharging spring water and the surrounding sea water. Although the contrast is, in places, obscured by mixing of the fluids, a strong anomaly was recorded for the Naples springs.

RADAR-IMAGERY STUDIES

Radar systems have a day-or-night all-weather capability that produces an image resembling an aerial photograph taken with the sun at a low angle. Tonal variations in the images are dependent on the slope, particle size, and dielectric properties of the materials in the scene. Radar imagery is being studied to determine its utility as a tool for geologic, hydrologic, and geographic research. Preliminary results show that it is effective in enhancing many geologic features that are topographically expressed. This capability was found particularly useful in heavily forested areas of the Pacific Northwest, according to Arthur Grantz, E. W. Wolfe, and others.

R. G. Reeves and A. N. Kover report that more than 300,000 square miles of the United States has been imaged by side-looking radar (SLAR) systems under the cooperative program with NASA.

General studies in Western United States

Rowland Tabor found side-looking radar imagery useful in defining landforms composed of surficial deposits in the highly forested Glacier Peak Valcano area, Washington. P. C. Bateman and M. F. Sheridan found that differences in tone in alluvial materials were largely a function of grain size and density rather than soil-moisture content in the vicinity of Bishop, Calif. J. R. Cooper found that radar imagery obtained in a cross-polarized mode (as opposed to plane-polarized) revealed pyroxene rhyodacite outcrops as conspicuous dark spots in an alluvial plain. The outcrops have no topographic expression, had not been previously mapped, and were not visible on the plane-polarized image. This discovery, believed to be due to the high glass content of the rock, enabled Cooper to define a buried fault in the area, also not previously recognized. R. J. Roberts found that radar imagery revealed faults cutting through the Carlin mine area, Nevada, that had not been recognized during earlier mapping.

Radar imagery was also found to be useful in mapping surficial deposits and expression of features such as faults and fractures in the following areas by the following investigators: Salton Sea, Calif., by E. W. Wolfe; San Andreas fault zone, San Mateo and Santa Clara Counties, Calif., by R. D. Brown, Jr.; southwestern and central Utah by L. S. Hilpert; Yellowstone Park, Wyo., by R. L. Christiansen, K. L. Pierce, H. J. Prostka, and E. T. Ruppel; Spanish Peaks region, Colorado, by R. B. Johnson; southern Utah by R. J. Hackman; Meteor Crater, Ariz., by G. G. Schaber.

Rock types differentiated in Utah

R. J. Hackman (p. D135–D142) found that radar imagery of San Juan and Garfield Counties, Utah, was useful in distinguishing certain rock types. Calcareous and gypsiferous sedimentary rocks are shown as very light tones of gray, in contrast to sandstones and shales which appear as darker tones of gray. Fissile marine shales (dark tones) can be distinguished from sandstone members (light-medium-gray tones) of the Cretaceous Mancos Shale and some calcareous beds (light tones) in the lower part of the Mancos Shale. These contrasts are visible but less conspicuous on conventional aerial photography of the same area. On the other hand, many rock units readily distinguishable on the aerial photography can not be positively differentiated on the radar imagery.

ULTRAVIOLET STUDIES

Rock-type contrasts noted

W. R. Hemphill continued investigations of ultraviolet data acquired with an ultraviolet imaging scanner in the NASA supporting aircraft and by a multichannel scanner operated by the University of Michigan. He found that evaporite deposits near Mono Lake, Calif., selected sandstone beds in the Triassic Moenkopi Formation near Meteor Crater, Ariz., and Permian Kaibab Limestone near Cane Springs, Ariz., appear with greater contrast in the ultraviolet than at longer wavelengths.

Fraunhofer-line discriminator being developed

W. R. Hemphill and H. T. Betz and others of the Illinois Institute of Technology Research Institute are studying the use of a Fraunhofer-line discriminator to detect materials that are stimulated to luminescence by solar ultraviolet energy, and are designing an instrument for this purpose. Such an instrument potentially can be useful for (1) monitoring luminescent dyes, such as rhodamine B, that are used to measure streamflow and current dispersion, (2) the detection of certain bioluminescence associated with water pollution, and (3) the detection of phosphates and other minerals that are stimulated by the sun to ultraviolet luminescence.

CARTOGRAPHIC INVESTIGATIONS

In accordance with the cooperative research agreement between the U.S. Geological Survey and the

National Aeronautics and Space Administration, a study of the cartographic applications of ultra-high-altitude and space photography is underway.

Ultra-high-altitude photography-compilation evaluation

An experimental 100-foot-contour-interval topographic map of part of Clark County, Nev., was photogrammetrically compiled at a scale of 1:96,000 from 6-inch-focal-length photographs taken at a flight height of approximately 117,000 feet. The experimental map was evaluated by comparison with published 1:250,000-scale and 1:62,500-scale topographic maps. This comparison showed that, with limited field completion, the quality and completeness of the content would be suitable for 1:250,000-scale topographic maps but not for 1:62,500-scale. Accuracy tests indicate that the experimental map meets National Map Accuracy Standards for a contour interval of 80 feet at the scale of the compilation.

Panoramic-photography research

A research project is being conducted to evaluate the geometric fidelity of high-altitude transformed panoramic photography. Distortion parameters are determined by comparing a series of analog photogrammetric measurements with known ground-control information. Film reference marks are being analyzed to determine errors caused by the mechanical actions of the camera during exposure and errors caused by the transformation process. The objective is to derive data that will support formulation of optimum specifications for a complete panoramic photogrammetric mapping system (camera, transforming printer, and stereoplotter).

As an adjunct to this test, a prototype computer program for analytical determination of panoramic-photography distortions has been written and is being tested. Input data will be obtained from digitized monocomparator measurements of points on panoramic photographs.

Gemini-photography evaluation

Selected photographs taken during Gemini IV and VII missions were evaluated for resolution and application to small-scale mapping.

A stereopair of 80-mm-focal-length Gemini IV photographs covering the general area of Willcox, Ariz., was selected for study. As a result of microdensitometer-trace analysis and measurements on resolvable National Bureau of Standards targets, the resolution of third-generation color negatives was found to be 25 line-pairs per mm, sufficient for revision of planimetric detail at a scale of 1:250,000. Tests designed to determine the use of these photographs in a stereoplotter were only partially successful because the tilt of the photographs was more than could be accommodated in the test instrument.

Analysis of the 250-mm-focal-length Gemini VII photographs of the Cape Kennedy, Fla., area showed that the ground resolution was equal to that of the Gemini IV photographs of the Willcox, Ariz., area. The expected resolution advantage of the longer focal length Gemini VII photographs was not apparent because of the increased orbital height (apogee) and relatively poor atmospheric conditions at the time of exposure.

Gemini photographic studies clearly demonstrate the cartographic potential of space photography. If specially designed cartographic camera systems are used, space photography should have great value for map revision and small-scale mapping.

Panoramic-stereoplotter design study

A project is underway to investigate the use of conventional-type photogrammetric stereoplotters for extraction of cartographic data from panoramic photographs. The object is to determine specifications for modification of a state-of-the-art stereoplotter or for a new stereoplotter that will be economical to build, will accommodate enlarged transformed panoramic photographs, and will utilize the high resolution of panoramic photography. Preliminary studies indicate that the modification of an optical-train-type stereoplotter (as opposed to the direct-optical-projection type) offers the greatest potential.

For more immediate use in the research effort, a direct-optical-projection-type stereoplotter, capable of utilizing 12-inch-focal-length metric photography, will be obtained in the near future to exploit this type of photography.

Surveyor photography restitutor

The Surveyor Photo Restitutor, a special direct-projection anagylphic instrument which forms large-scale stereomodels of the lunar surface from photographs obtained by the Surveyor spacecraft, was designed and built in 7 months and delivered to the Branch of Astrogeology, Flagstaff, Ariz., in May 1967. Much design and shopwork was saved by incorporating elements from surplus photogrammetric equipment.

EARTH RESOURCES OBSERVATION SATELLITE (EROS)

The Earth Resources Observation Satellite (EROS) Program, announced by Secretary of the Interior Stewart L. Udall on Sept. 21, 1966, and conceived with the support of NASA, is an integrated U.S. Department of the Interior program to utilize space-acquired remote-sensor data in its resource activities. William T. Pecora, the Director of the U.S. Geological Survey, will direct the EROS program and the Geological Survey will act as the leading agency for the program. Initial data requirements and a wide variety of possible applications were defined by many bureaus within the Department as well as by the U.S. Department of Agriculture and the oceanographic community. Specifications were developed for the first EROS satellite and, in cooperation with this effort, NASA conducted an advanced-mission study to determine the most appropriate satellite and instrument configuration to best meet the initial needs of the EROS program. A cost-benefit analysis of the use to be made of the data expected to be acquired was initiated by contract to the Westinghouse Electric Corporation. It is planned that the first operational EROS satellite will bear three television cameras in near-polar sun-synchronous orbit.

EARTHQUAKE STUDIES

The earthquake-studies program of the U.S. Geological Survey is coordinated by the National Center for Earthquake Research, Menlo Park, Calif. The program includes geological and geophysical investigations of earthquake-fault zones, instrumentation of earthquake-fault zones, research on the physics of the earthquake mechanism, and research in geology and geophysics as applied to earthquake engineering.

GEOLOGIC INVESTIGATIONS

Rate of creep on San Andreas fault

During the June through August (1966) series of seismic events in the Parkfield-Cholame area of central California, R. E. Wallace and E. F. Roth analyzed progressive slippage or tectonic creep along the San Andreas fault and found that displacements were right-lateral strike slip and that rates ranged from 1 inch per day the first day after the earthquake to 0.01 inch per day after a month. Analysis of evidence of historic displacement—for example, misalinement of fences—indicated a long-term rate of between 43 and 80 inches per century, a rate sufficient to account for hundreds of miles of strike slip during the Tertiary period.

Surface fracture in Parkfield, Calif., area

Field examination by R. D. Brown, Jr., and J. G. Vedder (Brown and others, r1671) discloses that approximately 23 miles of surface fracture of the San Andreas fault zone accompanied moderate (magnitude 5.5) earthquakes of June through August 1966 in the vicinity of Parkfield, central California. The surface fracturing closely follows a line of earlier faulting, which is marked by a variety of topographic and geologic features. The extent of surface fracture, which is unusually large for earthquakes of moderate magnitude, suggests relatively shallow focal depths.

Recent fault features along San Andreas fault zone

Geologic interpretation by D. C. Ross of a new set of 1:12,000-scale aerial photographs along the San Andreas fault zone from Tejon Pass to Cajon Pass in southern California has delineated features associated with the most recent movements along the San Andreas fault. Generally there is only one prominent fault trace in a given area, which is marked by well-preserved scarps, sags, and other evidence of recent movement, and the fault traces are a series of en echelon segments mostly 2½ to 5 miles long, rather than a single continuous fault trace. The fault features suggest to Ross that the ground along much of the fault was broken during the 1857 (Fort Tejon) earthquake.

Possible basis for determining major-earthquake intervals, Gulf of Alaska

Studies of displaced shorelines along the coast of the Gulf of Alaska by George Plafker and Meyer Rubin have revealed a history of complex Holocene tectonic movements. Net postglacial emergence of as much as 55 m and submergence of at least 90 m relative to sea level has occurred in contiguous areas within the zone that was affected by tectonic uplift and subsidence during the 1964 earthquake. For 930 years (carbon-14 date), and possibly for as long as 1,360 years (carbon-14 date) prior to 1964, gradual submergence of as much as 4.2 m affected much of the coast—both in the zone that was uplifted and in part of the zone that subsided during the earthquake. The duration of this interval of gradual preearthquake submergence is believed to indicate the approximate length of time since the last major tectonic earthquake. Further studies of emergent and submergent shorelines in this region are planned and may provide a basis for determining recurrence intervals of major tectonic earthquakes at specific coastal localities.

GEOPHYSICAL INVESTIGATIONS

San Andreas fault system instrumentation

A network of nine short-period seismographs has been established in the vicinity of Menlo Park, Calif., by the National Center for Earthquake Research (NCER). Eight of the stations are astride the San Andreas fault in the Santa Cruz Mountains southwest of Menlo Park, and the ninth station is at Coyote Hills, across San Francisco Bay east of Menlo Park. Signals from all stations are telemetered via commercial telephone lines from the field locations to NCER headquarters in downtown Menlo Park, and recorded there. Very few local earthquakes are recorded from sources within the network. Most local earthquakes recorded have sources in the San Andreas fault system in the vicinity of Hollister, southeast of Menlo Park, or from sources in the Hayward-Calaveras fault system east of Menlo Park. Earthquakes from more remote locations are also recorded on the network.

The short-period seismograph network is being extended to a total of 31 stations. Twenty-five of these stations will be in the San Francisco Bay area, for study of local earthquakes on the San Andreas, Hayward, and Calaveras faults. Six stations will be in the Parkfield-Cholame area, for study of local earthquakes on the San Andreas fault in the vicinity of the Parkfield-Cholame earthquakes of June through August 1966. All stations will be linked by telephone lines to NCER. Experiments are in progress to add recording tiltmeters, gravity meters, and magnetometers to the instrumental networks. Experimental Geodimeter networks to study crustal strain have also been established and are being repeatedly observed at critical locations along the San Andreas and associated faults in coastal California.

California aftershock studies

J. P. Eaton has made a detailed study of the aftershocks of the Parkfield-Cholame earthquakes of June through August 1966 in Monterey and San Luis Obispo Counties. Using a network of portable short-period seismographs and the results of a detailed seismic survey of velocity variations in and adjacent to the San Andreas fault zone, Eaton has determined that the aftershocks occur on or very near a fault surface that extends vertically downward from the surface break to a depth of about 12 km. First-motion studies are compatible with the right-lateral strike slip observed on the surface break.

R. W. Greensfelder has used a network of portable short-period seismographs to study the aftershocks of the Truckee earthquake of September 12, 1966, in northeast California. He found that the aftershocks occur in a narrow vertical zone 3 km wide, 10 km long, and extending to a depth of 12 km. The zone trends about N. 30° E. within the zone of surface deformation observed by Reuben Kachadoorian, R. F. Yerkes, and A. O. Waananen. First-motion studies suggest reverse faulting along planes striking about N. 70° W.

Denver earthquake studies

J. H. Healy and D. B. Hoover have continued their studies of the earthquakes associated with the injection of waste fluids in the Rocky Mountain Arsenal well northeast of Denver, Colo. Although disposal of waste fluids was terminated in early 1966, earthquakes have continued to occur, notably in November 1966 and February and April 1967. The strongest of these earthquakes, that of April 10, 1966, had a Richter magnitude of about 5. This earthquake caused minor damage and was felt over a wide region.

Using a network of seventeen short-period seismographs at the Rocky Mountain Arsenal, supplemented by temporary portable stations, Healy and Hoover have determined that all earthquakes, including the prominent one of April 10, occurred within a few kilometers northwest of the well in the elliptical zone previously defined. The zone trends about N. 65° W. The aftershocks of the April 10 earthquake were northwest of the well in a narrow linear pattern with this same trend. Focal depths of the earthquakes range from 4 to 7 km.

A detailed seismic-reflection survey disclosed no evidence for faults within the sedimentary section, but it is possible that faults with small vertical displacements might have been missed. Reflections from horizons within the Precambrian basement rocks reveal prominent dipping structures, with the possibility of significant fault displacements.

ENGINEERING GEOLOGY

Puget Sound, Wash., earthquake

Studies by D. R. Mullineaux and others (p. D183–D191) of building damage in Seattle caused by the Puget Sound earthquake of April 29, 1965, indicate a poor to good correlation between damage intensity and surface geology. The earthquake had a magnitude of about 6.5 and a focal depth of about 60 km. In general, damage was mild for an earthquake of this magnitude in a heavily populated area, although it was widespread in the central part of the Puget Sound lowland. Damage was most severe generally in areas of wet poorly consolidated alluvium, beach sand, and artificial fill. However, one area of relatively severe damage is directly underlain by compact Pleistocene sediments, a type of material on which only minor damage occurred elsewhere in the city. The cause of this locally intense damage, apparently unrelated to surface geology, is not known, but it might be due to the shape or structure of bedrock at depth, either of which might have modified the distribution of earthquake energy.

Intensity of Parkfield-Cholame, Calif., earthquakes

Earthquake intensities of VIII to IX resulted from the strongest shock (magnitude 5.5) of the Parkfield-Cholame earthquakes in June 1966 along the San Andreas fault in central California. According to R. F. Yerkes and R. O. Castle (r1672) these intensities correlate well with a measured acceleration of 0.5 acceleration of gravity normal to the trend of the associated fracture zone, but not with the relatively small magnitude of 5.5. Previous shocks of this magnitude commonly have been associated empirically with accelerations of about 0.07 acceleration of gravity and epicentral intensities of VI to VII. The effects of the strongest shock indicate that the potential destructiveness of shocks in the same magnitude range should be reappraised, especially for areas underlain by poorly consolidated materials along faults of the San Andreas type.

Investigation of Taltal earthquake, Chile

R. W. Lemke and Ernest Dobrovolny, in cooperation with geologists of the Chilean Institute of Geological Investigations, studied the effects of the Taltal earthquake of December 28, 1966, to relate earthquake damage of manmade structures to different types of ground materials.

The surface effects at Taltal were found to be comparatively minor for an earthquake having a reported magnitude of 7¾, probably in part because of the considerable depth of focus. Small fractures 3 to 7 m long and 1 to 3 cm wide broke the ground surface intermittently along the traces of the major fault zones for a distance of about 25 km in the vicinity of Taltal. Inasmuch as there were no apparent horizontal or vertical offsets, fracturing may have resulted from greater ground motion along planes of weakness in the fault zones. Minor slumping occurred on a few natural slopes and in some cuts and fills along highways. Some mine dumps and tailing ponds locally developed fractures and slumps. Ground fracturing and minor rock falls were associated with a few open-pit mines, but no damage was reported in underground workings.

The few buildings in Taltal that were constructed on bedrock sustained no apparent damage. However, 250 buildings constructed on alluvium were severely damaged. Most of these were constructed of inferior materials and were not designed to resist strong ground motion.

During January 1967, A. M. Pitt and J. O. Ellis, in cooperation with the University of Chile, recorded aftershocks from the Taltal earthquake. Four battery-powered portable seismograph systems were sent to Chile and were set up in a network with 30 to 50 km between stations. Efforts were directed toward accurate determination of depth of focus and improvement of east-west control on epicenters over that provided by the permanent seismograph network of the University of Chile. Seventy-five to 100 earthquakes of magnitude 2 or greater were recorded on this network each day. Preliminary analysis of data indicates that the aftershock zone extended for 70 km in a north-south direction, approximately 30 km off the coast near Taltal.

Investigation of Varto earthquake in eastern Turkey

At the invitation of the Government of Turkey and in cooperation with the Minerals Research and Exploration Institute of Turkey, R. E. Wallace investigated the effects of the Varto earthquake of August 17, 1966.

The area of maximum intensity centered near Varto and extended for at least 10 km southward. The southeast-northwest extent may have been as much as 60 km. The intensity within this area reached IX, but many damage effects might be classified as only VIII. According to reports from the Turkish Government, 2,529 people were killed, 1,500 were injured, and 19,013 buildings were destroyed or heavily damaged.

The surface fracturing that accompanied the earthquake indicates that the Varto earthquake was related to the North Anatolia fault system. Fractures arranged in an en echelon pattern characteristic of right-lateral strike slip were found, but many other fractures in three main fracture zones displayed extension normal to the factures.

Examples of situations in which geologic factors influenced damage include: (1) at Sazlica, surface tectonic fractures passed under buildings; (2) at Tepekoy, landslides covered a highway; and (3) at Varto, greater damage was done to buildings situated on water-saturated alluvium as compared to buildings situated on adjacent higher bench gravels.

THE 1964 ALASKA EARTHQUAKE

On March 27, 1964, one of the most violent earthquakes of all time rocked south-central Alaska. The death toll was comparatively light, but thousands were left homeless, more than 50,000 square miles of the State was tilted, and property damage disrupted the Alaska economy. With many other agencies, government and private, the U.S. Geological Survey immediately began field studies of the earthquake and its effects. The results of these studies, which involved many man-years of concentrated effort, are now being reported in a series of Professional Papers that will together comprise a comprehensive description of all geologic and hydrologic aspects of the earthquake. Eighteen reports in this series had been published by the end of fiscal-year 1967.

Reports on Alaska earthquake

An introduction to the account of this violent earthquake is presented in words and pictures, many of them in color, in Professional Paper 541 (W. R. Hansen and others, r1036). The geologic setting and effects of the earthquake are summarized by Hansen and E. B. Eckel in terms understandable to laymen as well as specialists. Hansen also describes the Survey's field investigations, and Eckel and W. E. Schaem the work of the Scientific and Engineering Task Force, which represented a significant effort to apply earth-science knowledge to policy decisions in a disaster area. The extensive and crucial activities of the U.S. Army Corps of Engineers, both during the early cleanup period and during later reconstruction, are described by Corps of Engineers authors R. E. Lyle and Warren George. Genie Chance, a public-relations consultant, summarizes the events of the year following the earthquake and tells how Alaska rose from the ruins.

Seward, one of the few year-round ports in south-central Alaska and a main rail terminal, lost nearly all of its waterfront to gigantic submarine slides, waves, and fire. The bearing of local geology on earthquake effects and on plans for relocation of port facilities are described by R. W. Lemke (r1615). Kodiak and the nearby Kodiak Naval Station were hard hit by a series of seismic sea waves that followed general land-level subsidence (Reuben Kachadoorian and George Plafker, r1976). Except for a report on smaller towns, still in preparation, the Seward and Kodiak reports complete the volume on the earthquake's effects on communities.

Additional contributions on regional effects of the Alaska earthquake of 1964 appear in reports on the Martin–Bering Rivers area (S. J. Tuthill and W. M. Laird, r0897) and on the Copper River Basin area (O. J. Ferrians, Jr., r0395). Both of these vast areas are thinly populated, but cracks in soil and ice, landslides, and other permanent or transitory geomorphic effects were widespread. A gravity survey of the Prince William Sound epicentral region, which provides needed background data for future students of the earthquake, is described by J. E. Case and others.[71] Kodiak and several smaller nearby islands, with numerous native villages and canneries, are in the westerly part of the earthquake-affected zone that subsided several feet. As at the town of Kodiak, nearly all the damage throughout the island group was caused by subsidence and by seismic sea waves (George Plafker and Rueben Kachadoorian, r0898).

The earthquake had only minor, and mostly transient, effects on stream and lake waters in south-central Alaska, but ground-water supplies throughout the region (R. M. Waller, r0396) and in the vicinity of Anchorage (R. M. Waller, r0397) were strongly affected in many places. The principal effects were changes in water levels in wells, some of which recovered quickly whereas others were extremely slow.

Widespread spouts of water and mud issued from ground fissures. Many wells were muddied by vibrations, but the principal changes in chemical quality took place where tectonic subsidence allowed invasion of sea water. Fluctuations were noted in well-water levels not only in Alaska, but throughout the conterminous United States and even at points as distant as the Caribbean islands and parts of Europe (R. C. Vorhis, r1975).

Glaciers, which feed all the streams in the earthquake-affected area, cover 20 percent of the area. Studies by Austin Post (r1977) show that there were no large avalanches of snow or ice, but many rockslide avalanches, some of which will have long-lasting effects on the glaciers. Post also found evidence to disprove a long-held theory that earthquakes tend to speed up the rate of glacier advances.

The first two chapters of a volume on transportation and utilities were published during the year; chapters on the severely damaged highway and railroad systems are in preparation. The first chapter, by U.S. Bureau of Reclamation authors, describes the vibration damage to the intake structure and other facilities of the Bureau's Eklutna Hydroelectric Project, and includes a section on a unique adaptation of television to examination of breaks in underground utility ducts (M. H. Logan, r1037). The second chapter summarizes the effects of the earthquake on air and water transport, communications, and utilities systems throughout the stricken area. The damages to these systems, though crippling at the time, were largely repaired in a short time, according to E. B. Eckel.[72]

Committee on Alaska earthquake

Through membership on the committee itself and on several of its panels, the Geological Survey continued its active support of work done by the Committee on the Alaska Earthquake, National Academy

[71] J. E. Case, D. F. Barnes, George Plafker, and S. L. Robbins, 1966, Gravity survey and regional geology of the Prince William Sound epicentral region, Alaska: U.S. Geol. Survey Prof. Paper 543–C, p. C1–C12.

[72] E. B., Eckel, 1967, Effects of the earthquake of March 27, 1964, on air and water transport, communications, and utilities systems in south-central Alaska: U.S. Geol. Survey Prof. Paper 545–B, p. B1–B27. [Published July 1967]

of Sciences. This committee is preparing a comprehensive report on all physical- and social-science aspects of the earthquake; volumes now planned include studies of human ecology, engineering, seismology, geology, hydrology, oceanography, and biology. Emphasis will be on effects and lessons of the Alaska earthquakes as these bear on the greater national problem of coping with future earthquakes. Most of the Geological Survey's Professional Papers on the earthquake will be reprinted in one or another of the Academy's volumes, which will also include several topical papers prepared for the committee by Survey authors.

GEOPHYSICAL INVESTIGATIONS

STUDIES OF THE CRUST AND UPPER MANTLE

SEISMIC STUDIES

Project EARLY RISE

Twelve university, government, and private geophysical-research institutions from Canada and the United States joined forces in July 1966 with eight supporting Canadian, United States, and State Government agencies to conduct a detailed seismic exploration of the earth's upper mantle from explosive sources in Lake Superior. The huge international cooperative experiment, identified by the code name PROJECT EARLY RISE, was coordinated by the U.S. Geological Survey on behalf of the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense as a part of the VELA-UNIFORM program. Approximately 2,000 seismograms were recorded from a total of thirty-eight 10,680-pound shots in Lake Superior along 7 lines which in effect provided seismic coverage of the entire North American Continent. Seismic recordings were made to distances as great as 3,000 km.

Interpretation of the traveltimes and amplitudes from the seismic recordings will provide the first detailed definition of the compressional-wave (and possibly also the shear-wave) velocities in the outer 1,000 km of the earth's mantle, the so-called upper mantle of the International Upper Mantle Project.

The following Canadian, United States, and State agencies and institutions assisted in planning and preparing for the experiment: the U.S. Department of State, the Department of External Affairs of Canada, the U.S. Bureau of Commercial Fisheries, the Michigan, Minnesota, and Wisconsin Conservation Departments, the Observatory Branch of the Department of Energy, Mines, and Resources of Canada, and the Arctic Institute of North America.

Shots were fired by U.S. Navy Explosives Ordnance Disposal Unit No. 2 from aboard the USCG cutter *Woodrush*. The U.S. Coast Guard provided all ship support for the operations.

The following Canadian and United States geophysical-research institutions participated in the recording program: University of Alberta, U.S. Geological Survey, University of Manitoba, University of Michigan, Southwest Center for Advanced Studies, Stanford Research Institute, University of Toronto, University of Western Ontario, University of Wisconsin, and the Air Force Technical Applications Center (AFTAC). The Geological Survey was assisted by the United Geophysical Corporation, and AFTAC was assisted by the Geotech Division of Teledyne Industries.

Two reports, incorporating all shot locations, traveltimes, and amplitudes, have been prepared by the Geological Survey with the assistance of the University of Wisconsin and the United Geophysical Corporation, and transmitted to ARPA and all participants. Data from these reports will be analyzed by the participants and published in scientific journals.

Earlier international cooperative experiments using explosive seismic sources in Lake Superior were conducted in 1963 and 1964. The 1963 experiment was coordinated by the Carnegie Institution of Washington; the 1964 experiment was coordinated by the Geological Survey.

LASA calibration

Cecelia Borcherdt and John C. Roller have found additional evidence that the crust thins from the Great Plains into the Northern Rocky Mountains by interpretation of a southwest-trending seismic-refraction profile through the Large Aperture Seismic Array (LASA), Montana. The Mohorovicic discontinuity is about 50 km deep in the Great Plains and about 40 km in the Northern Rocky Mountains. The seismic experiment, the first of a two-phase calibration of the LASA on behalf of ARPA, was combined with aeromagnetic and gravity surveys of the surrounding region. The aeromagnetic and gravity surveys revealed the presence of large lithologic contrasts in the crust in the vicinity of the LASA that may be related to local seismic-traveltime anomalies that have been noted on the array.

The evidence from this experiment of crustal thinning associated with mountain structure provides additional proof that isostatic compensation is not controlled by crustal thickness alone but by a combination of crustal thickness and crustal and upper-mantle density variations.

AEROMAGNETIC AND GRAVITY STUDIES

Continental aeromagnetic studies

Isidore Zietz and Elizabeth King have analyzed aeromagnetic anomalies in a transcontinental band about 100 miles wide and find evidence for contrasting crustal properties west and east of the Rocky Mountains.

For the western conterminous United States, large crustal units are characterized by distinct magnetic patterns in the Coast Ranges, Central Valley of California, Sierra Nevada, Basin and Range province, Wasatch Range, and Rocky Mountains. In the Basin and Range province, although topographic features are predominantly north trending, the magnetic features are predominantly east trending. Of economic significance, anomalous magnetic patterns are associated with the Ely, Bingham, and Tintic mining districts of Nevada and Utah. This may prove to be important in the search for the extension of existing mining districts, and points the way for detailed geological, geophysical, and geochemical investigations. East-trending lineaments, some as long as 400 miles, are clearly discernable on the aeromagnetic maps. These lineaments may be associated with large fractures in the earth's crust.

For the eastern United States, the aeromagnetic maps demonstrate the feasibility of using aeromagnetic surveys for mapping gross lithologic units and determining trends of major features of the basement rocks. The striking linearity of the anomalies over the Blue Ridge and Piedmont rocks and the late Precambrian mafic rocks contrasts markedly with the more amoeboid pattern over the magnetic areas of Nebraska, eastern Iowa, and central Ohio.

Gravity studies in California

A complete Bouguer gravity map of California between lat 35° N. and lat 39° N. has been compiled at a scale of 1:1,000,000 by H. W. Oliver and the California Division of Mines and Geology. The map has a contour interval of 10 mgals derived from gravity measurements at more than 20,000 stations. A comparison with the California part of the 1:2,500,000 gravity map of the United States published by the Geological Survey in 1965 suggests the following significant changes: (1) gravity over the Coast Ranges is not featureless but has a characteristic grain parallel to the northwest-striking structures, (2) a major lineament of gravity highs extends about 80 miles southeastward from Fresno to Porterville, and (3) a nearly circular gravity low with a half width of 5 miles occurs in the geyser and hot springs area south of Clear Lake in the Coast Ranges. This anomaly, which cuts across surface geologic features, may be of magmatic origin.

W. F. Hanna has made gravity measurements over the intersection of the San Andreas, Garlock, and Big Pine fault zones, and over the Tehachapi Mountains in the vicinity of the Garlock and White Wolf fault zones. A gravity high of 55 mgals is centered on the north side of the San Andreas fault where the fault's surface trace is deflected easterly near the intersection of the Garlock and Big Pine faults. Steep gravity gradients roughly delineate the surface traces of the White Wolf and Garlock fault zones near the flanks of the Tehachapi Mountains. Gravity values over plutonic rocks in the Tehachapi Mountains are as much as 70 mgals higher than values over plutonic rocks in the southern Sierra Nevada 40 miles to the northeast, thus suggesting appreciable differences in isostatic compensation of the rock masses.

ROCK DEFORMATION

E. C. Robertson reports that occurrence in the upper crust of the earth of high-pressure minerals such as aragonite and jadeite is evidence that high stresses exist there; other indirect and direct evidence of this can also be adduced. The argument that rocks near the surface are too weak to support high tectonic stresses can be countered by experimental results; a 5-fold increase in strength is induced by applying 3 kb confining pressure to massive rocks. Weakening of rocks to about 25 percent of their maximum strength can occur with heating at 300°C and deformation at a geologic strain rate of 10^{-13} sec^{-1}. High pressure of pore water could remove all strength, but as high pore pressure is not observed in massive rock in deep holes, its effect may be neglected. Assuming that vertical stress is due to superincumbent load, and that experimentally determined rock strength defines the lateral stresses, mean stresses at 10 km depth could range from 5 kb for low-strength rocks to 12 kb for high-strength rocks. If mean strength is equated with hydrostatic pressure, and the temperature is assumed to be 200°C, the transition of calcite to aragonite would occur at a depth of 23 km if the rock containing the carbonate had no strength and acted as a fluid under hydrostatic stress. It would occur at 13 km or deeper, of course, if the rock had low strength; it would occur at 4 km or deeper if the rock had a high strength.

C. B. Raleigh has established a modern high-pressure rock-deformation laboratory at the National Center for Earthquake Research in Menlo Park, Calif. He is investigating the deformation and failure of crustal and upper-mantle rocks associated with earthquake mechanisms and, in a study of planetary geophysics, the deformation of meteoritic materials.

CRUSTAL PROPERTIES AND EVOLUTION

Phase changes, subsidence, and uplift

A numerical method has been devised by W. B. Joyner for testing the consequences of the hypothesis that an isochemical phase change exists at the Mohorovicic discontinuity. The method, like the one recently developed by W. J. van de Lindt [73], takes into account the effects of isostasy, which have been neglected in earlier work. The results of calculations indicate that a phase change, if present, can account for the deposition of great thicknesses of sediments over long periods of time in relatively shallow water basins. Such deposition is a geologic observation of fundamental significance, and it is difficult to explain in other ways. For models in which clastic deposition was assumed and the initial basin depth was 1.5 km, 7 to 10 km of sediments was deposited depending on deposition rates and other parameters. With an initial depth of only 500 m, 4 km of clastic sediments was deposited or 6 km of limestone. For the models studied, the time span of deposition was as long as 40 m.y. for clastic sediments and 200 m.y. for limestone. In all cases, deposition was followed by uplift.

Oceanic crust

A. E. J. Engel and his associates estimate that the oceanic crust consists (in volume percent) of 14 percent sediments; 50 percent oceanic theoleiite; 19 percent greenschist; 15 percent serpentine and 2 percent other rocks. The average concentration of potassium in this crust is less than 800 ppm; of uranium, 0.1 ppm; and of thorium, 0.2 ppm. More than 7×10^7 cu km of oceanic tholeiite has been extruded along the ridges and rises in the last 50 m.y.

Continental crust

L. C. Pakiser and Rhoda Robinson (r1452) have estimated the average properties of the continental crust of the United States on the basis of seismic-refraction observations in 7 provinces comprising the area in and west of the Rocky Mountains and 3 province groups comprising the larger area east of the Rocky Mountains. They report that the average crustal thickness in the tectonically active western part is about 34 km, of which the upper 19 km consists of rocks of predominantly silicic composition, and the lower 15 km consists of rocks whose predominant composition is probably mafic. In the tectonically stable eastern part, the average crustal thickness is about 44 km, of which the upper 19 km consists of rocks of predominantly silicic composition and the lower 25 km consists of rocks whose predominant composition is probably mafic. Hence, silicic rocks predominate in the west and mafic rocks in the east. The average crustal thickness of all provinces is about 41 km, of which 55 percent is estimated to be mafic in composition. These observations can be explained in part by a process of crustal thickening through the addition of mafic as well as some silicic material from the mantle, accompanied by removal of silicic material from the upper surface of the crust by erosion. They provide additional proof that isostatic compensation is controlled in large part by mantle density variations and suggest a dynamic mechanism associated with the vertical and lateral transfer of molten basalt for tectonic and isostatic balance.

According to A. E. J. Engel and associates, the oldest granites (1 eon or more) in the continental crust are largely derived by partial or complete melting and differentiation of a zone in the mantle 100 to 500 km or more thick. This conclusion follows from (1) the large volume of granites, (2) their high concentrations of potassium, uranium, and thorium, (3) their relatively low concentrations of strontium-87, and (4) the low concentrations of potassium, uranium, thorium, and strontium–87 in associated basaltic and ultramafic rocks of the old crusts and hence the low concentrations of these elements in their inferred mantle source regions.

A. H. Lachenbruch has studied mathematical models of crustal and upper-mantle temperatures in the Sierra Nevada, Calif., and from these studies concludes that upward concentration of uranium, thorium, and potassium accompanying plutonism could reduce deep crustal temperatures by as much as 200°C, enough to terminate igneous activity.

THEORETICAL AND EXPERIMENTAL GEOPHYSICS

New geomagnetic chronology data from Nunivak Island, Alaska

New data from volcanic rocks on Nunivak Island have helped to improve and extend the accuracy of the time scale for geomagnetic reversals. A new transition from reversed to normal polarity at 4.86 m.y. was found by A. V. Cox, G. B. Dalrymple, J. M. Hoare, and W. H. Condon; the existence of the Jaramillo normal event lasting from 1.0 to 0.86 m.y. ago was confirmed; and several of the previously recognized polarity epoch boundaries were defined with greater precision. The most recent volcanic episode on

[73] W. J. van de Lindt, 1967, Movement of the Mohorovicic discontinuity under isostatic conditions: Jour. Geophys. Research, v. 72, p. 1289–1297.

Nunivak Island began 0.9 m.y. ago with voluminous outpourings of tholeiitic basalt from widely spaced eruptive centers. The tholeiitic volcanism ended abruptly 0.3 m.y. ago. Eruption of strongly undersaturated alkalic basalt began shortly before the end of the eruption of tholeiite and has continued to the present time. The volume of the alkalic basalt is approximately 2 percent that of the tholeiite. During the past 6 m.y. there have been 5 episodes of tholeiitic volcanism and 4 of alkalic volcanism. The timing of the volcanism in this continental area is similar to that of the Hawaiian Islands, as is the petrology, suggesting that similar processes of petrogenesis occur in these two areas.

Mesozoic paleomagnetic field in North America

A paleomagnetic pole position for latest Jurassic–earliest Cretaceous time for North America has been obtained from radiometrically dated igneous rocks of the Sierra Nevada, Calif., by C. S. Grommé, with R. T. Merrill and John Verhoogen, both of the University of California. Grommé has also determined a pole position from preliminary measurements of ultramafic rocks from southeastern Alaska, which have been dated at about 100 m.y. by M. A. Lanphere using the potassium-argon method. When these are compared with other paleomagnetic poles already obtained from radiometrically dated igneous rocks in North America, it is found that (1) the geomagnetic field appears to have been predominantly dipolar during most of Cretaceous time, and (2) apparent polar wandering relative to North America did not occur during the period of geologic time from about 140 m.y. to about 85 m.y. ago but was rapid during comparatively short intervals before and after that time. Furthermore, because the periods of inferred rapid polar wandering relative to North America clearly do not coincide in time with similar periods for Australia and for Africa, it now appears that all the apparent polar wandering is due to continental drift and that polar wandering as an independent process does not occur.

Paleomagnetic pole of Triassic diabase from Pennsylvania

M. E. Beck, Jr., has continued paleomagnetic studies of Triassic diabase from southeastern Pennsylvania. Magnetically cleaned samples (464) from 97 different localities define a paleomagnetic pole at lat 62° N., long 104° E. This pole, along with previous work, also suggests a dipolar field for Triassic times.

Strength of Devonian magnetic field

P. J. Smith (p. D164–D168) has studied 280 samples from 73 Scottish Carboniferous and Devonian basalt lava flows to determine the intensity of the ancient geomagnetic field. All but three samples (from two flows in the Lower Old Red Sandstone) were rejected as unsuitable because of instability of natural remanent magnetization (NRM) alteration in the magnetic minerals during the heating necessary to induce an artificial thermoremanent magnetization (TRM), or remagnetization (probably chemical), since the flows were formed. The samples from the two remaining flows indicated ancient geomagnetic dipole moments of 0.75 and 0.34×10^{25} gauss cu cm, which are considerably smaller than the present dipole moment (8.0×10^{25} gauss cu cm).

Elastic moduli of quartz at high pressure

Louis Peselnick and Robert Meister, using a newly developed facility, have extended elastic moduli measurements on quartz up to 15 kb. The extension to higher pressures shows that the anomalous behavior (decrease in elastic constants with increasing pressure) for quartz continues for the shear modulus while the longitudinal modulus begins to approach the behavior of "normal" solids. These data indicate that the volume processes (compressibility) are more sensitive to pressure than the distortional processes, with respect to changes in fused SiO_2 structure.

SOLID-STATE STUDIES

MAGNETIC PROPERTIES OF MINERALS

Rhodizite

The formula $CsB_{12}Be_4Al_4O_{28}$ has been proposed [74] for the mineral rhodizite. For this formula to hold, the cesium or the substituting alkali atoms would have to be present in the neutral state. In collaboration with Dr. Gabrielle Donnay (Geophysical Laboratory, Carnegie Institution of Washington) and Dr. R. R. Sioda (Johns Hopkins University), A. N. Thorpe and F. E. Senftle have proved the absence of neutral cesium atoms by using electron-spin-resonance and magnetic susceptibility measurements (Gabrielle Donnay and others, r1003). The ionic formula $CsB_{11}Be_4Al_4O_{26}(OH)_2$ is proposed for rhodizite.

Tourmaline

A. N. Thorpe, F. E. Senftle, and Sherman White have continued the preliminary magnetic studies reported previously (*in* U.S. Geol. Survey, r0892) for various forms of tourmaline. The experimental results have been reported (Gabrielle Donnay and others

[74] M. J. Buerger and Karlheinz Taxer, 1966, Rhodizite—Structure and Composition: Science, v. 152, p. 500–502.

r1383), and show that the antiferromagnetic properties of tourmaline are due to a unique structural cancellation of the magnetic vectors of the iron atoms. An attempt is being made to work out a theoretical model to explain the results.

Zircon

C. C. Alexander, A. N. Thorpe, and F. E. Senftle have made preliminary magnetic-susceptibility measurements of gem zircon with different degrees of metamictization down to temperature of 77°K. Differences have been found, but insufficient work has been done to warrant interpretation.

TEKTITES AND GLASSES

Iron in tektites

F. E. Senftle and A. N. Thorpe are continuing their studies of submicroscopic metallic iron spherules in tektites. Various extraction techniques have been tried, but oxidation takes place so rapidly that it is difficult to identify the extracted particles as metallic iron. The magnetic material extracted from the tektite glass has been variously reported by X-ray analysis to be α-iron, Fe_3O_4, or Fe_2O_3, depending on the method of extraction.

F. W. Oliver, Thorpe, and Senftle have also been studying the Moessbauer spectra of tektites. No correlation was found between the intensity of the iron peaks and the chemical iron analysis. However, a good correlation was found between the chemical iron and the quadrupole splitting or the f factor of specimens in a given strewn field. This indicates the similarity in composition and conditions of formation of specimens in a given strewn field.

Water in obsidians, tektites, and basaltic glasses

Using an infrared technique for water analysis, A. N. Thorpe and F. E. Senftle have examined the water content of various natural glasses. The method can be used to examine the distribution of water in a thin section of glass. Preliminary measurements have been made to date suggesting that the water content is lower along the aerodynamic leading edge of a tektite.

THERMOLUMINESCENCE OF MINERALS

J. E. Vaz has constructed extremely sensitive thermoluminescence equipment for examining a very small quantity ($\approx$ 10 mg) of material. Preliminary measurements have been made on specimens of zircon, apatite, sphene, and tektite glass. A correlation is being made with the magnetic measurements on the same specimens to study natural radiation damage processes.

EXPLORATION GEOPHYSICS

Automation of airborne geophysical surveys

A system has been developed by G. I. Evenden and others (p. D79–D84) for digital recording and processing of all geophysical data and navigation control obtained with the Geological Survey's Convair 240 aircraft. Outputs from the magnetometer, gamma-ray spectrometer, electromagnetic system, and the navigation equipment, including a Doppler navigation system, are digitized by means of shaft encoders and analog to digital converters. Data are sampled and recorded on magnetic tape at a rate of 10 samples per second. Computer programs have been written to fit the Doppler data to documentation points along flight paths and compute the flight path of the aircraft, to rectify profiles, to locate intersections of traverse and base lines, and to make drift corrections. The final program for aeromagnetic data produces a plot of flight path, intersections of desired contours with the flight path, and location of maximums and minimums along flight path.

Airborne electromagnetic system

Under the direction of F. C. Frischknecht, an Input airborne electromagnetic system has been installed in the Survey's Convair 240 aircraft and successfully test flown. With the Input system, a large loop, excited by half-sine-wave pulses of current, is used as a source. Secondary fields from currents induced in the earth are measured by a trailing receiver coil during the interval between pulses. After initial work in Mississippi using a 1-coil receiver, the system was flown in Maine using a 2-coil receiver. The results show that the system is an effective means of mapping near-surface conductive units such as black slates in Maine. Significant anomalies were recorded on test flights over a known geochemical anomaly in The Forks quadrangle, Somerset County, Maine. Subsequent ground electromagnetic measurements outlined two conductive zones interpreted as massive sulfide bodies.

Gamma-ray spectrometer system

The Geological Survey has developed a gamma-ray spectrometer system for use in airborne and ground surveys. The system measures gamma energy by the scintillation method with two 11½- by 4-inch thallium-activated sodium iodide crystals. Four single-channel pulse-height analyzers show relative variations in radioelement concentration on a strip-chart recorder. Energy spectra, which enable numerical calculations of radioelement concentration, are obtained with a multichannel pulse-height analyzer. The results are presented as total terrestrial radioactivity and the contribution of uranium, thorium, and potassium-40. J. A. Pitkin and C. M. Bunker report that results from airborne surveys in New England and Colorado and ground surveys in Nevada indicate that the spectrometer can be used in exploration for radioactive and nonradioactive minerals and in geologic mapping.

Borehole gravimeter

T. H. McCulloh, J. E. Schoellhamer, and E. H. Pampeyan, in cooperation with L. J. B. LaCoste and H. B. Parks of the industrial firm of LaCoste and Romberg, Inc., developed (p. D92–D100) and tested (p. D101–D112) the U.S. Geological Survey–LaCoste and Romberg borehole gravimeter system in the laboratory and at the Sante Fe Springs oil field, California. At Sante Fe Springs, measurements were made from the surface to a depth of 9,500 feet. Precision of the downhole measurements ranged between 0.008 and 0.02 mgal depending on such variables as depth, care in physical handling of the gravimeter, and operator experience. During routine operation in wells less than 10,000 feet deep, observations can be made at 100-foot intervals with a precision of ± 0.01 mgal at a rate of 300 to 500 feet per hour including base checks for drift control.

Geophysics in ground-water investigations

The application of combined gravity, seismic, and resistivity surveys in appraisal of quality and quantity of ground water in intermontane basins of the southwestern United States was demonstrated by A. A. R. Zohdy (r2112), and R. E. Mattick (p. D85–D91), and D. B. Jackson and D. L. Peterson at White Sands, N. Mex., and El Paso, Tex. Gravity data indicated the general distribution and thickness of sediments in the basin. Refraction seismic profiles provided more precise information on the thickness of the sediments and data on velocity interfaces in the basin fill. Resistivity soundings delineated the fresh-water–salt-water interface, other horizons in the basin fill, and the depth to basement.

New resistivity curve

A new theoretical curve was developed by A. A. R. Zohdy for the interpretation of minimum or double-ascending resistivity sounding curves. The curve is unique, and can be used for interpreting three-layer curves for any resistivity contrast provided the resistivity of the second layer is known and the resistivity of the third layer tends to infinity. The curve has proved useful in making quick and accurate interpretations of resistivity soundings in areas underlain by crystalline basement rock.

Geophysical surveys in northern Nevada

A geophysical survey of the Woods Hills area of northeastern Nevada by C. J. Zablocki (p. B145–B154) revealed magnetic and conductivity anomalies in an alluvium-covered area. The cause of these anomalies is believed to be quartz latite locally altered to a conductive clay. Electrical resistivity soundings made in the Gold Acres area of the Shoshone Range in north-central Nevada by C. J. Zablocki revealed an appreciable resistivity contrast between the two facies of lower Paleozoic rocks juxtaposed by the Roberts Mountain thrust. Although younger structures make interpretation of the resistivity soundings difficult, the method offers promise of being useful in detecting the thrust where it is concealed.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

FIELD STUDIES IN PETROLOGY AND GEOCHEMISTRY

Anatectic model for Sierra Nevada batholith

P. C. Bateman and J. P. Eaton have developed further the anatectic model for the origin of the Sierra Nevada batholith. The batholith is localized in the axial region of a complex faulted synclinorium that coincides with a downfold in the Mohorovicic discontinuity and in *P*-wave velocity layers within the crust. *P*-wave velocities are compatible with downward increase in the proportion of diorite, quartz diorite, and calcic granodiorite relative to quartz monzonite and granite in the upper crust, with amphibolite or gabbro-basalt in the lower crust, and with peridotite in the upper mantle. The synclinorium was formed in Paleozoic and Mesozoic strata during early and middle Mesozoic time in a geosyncline marginal to the continent. Calculations by A. H. Lachenbruch show that parent magmas of granodiorite composition could have formed in the lower half of the crust at depths of 25 to 45 km or more, primarily as a result of high radiogenic-heat production in the thickened prism of crustal rocks. Magma was generated at different places over a period of more than 100 m.y. as the locus of downfolding shifted. The magma rose into the upper crust because it was less dense than either rock of the same composition or residual refractory rocks. Refractory rocks and crystals that were not melted, and early crystallized mafic minerals that settled from the rising magma, thickened the lower crust. Wall and roof rocks settled down around, and perhaps through, the rising magma and provided space for its continued rise. Erosion followed each magmatic episode and may have amounted to 10 to 12 km since the Jurassic and 7 to 10 km since the early Late Cretaceous.

Biotites from Sierra Nevada batholith

F. C. W. Dodge has found that the composition of biotites from granitic rocks of the Sierra Nevada batholith defines a trend in the ternary system

$$KFe_3^{+2}AlSi_3O_{10}(OH)_2\text{–}KMg_3^{+2}AlSi_3O_{10}(OH)_2\text{–}KFe_3^{+3}AlSi_3O_{12}(H_{-1}).$$

This trend parallels, at slightly higher oxygen pressures, the trend suggested by D. R. Wones and H. P. Eugster for biotite compositions buffered by Ni–NiO. This relation indicates that the Sierran biotites crystallized in a system that was closed to oxygen.

Zonation of alkali feldspars in Rader Creek pluton, Boulder batholith, Montana

Detailed optical and X-ray study of alkali feldspars by R. I. Tilling shows that the granodioritic Rader Creek pluton, western Montana, is zoned with respect to the structural state of the feldspars. Computer-derived cell parameters indicate that the samples from the peripheral portions of the mass are highly ordered orthoclases, whereas samples from the interior are intermediate microclines. The monoclinic-triclinic inversion, as reflected by the behavior of the (131) reflections, indicates a first-order reaction; the triclinic (131) and $(1\bar{3}1)$ reflections are superimposed on the monoclinic (131). As the inversion proceeds to a lower structural state, the triclinic reflections increase at the expense of the monoclinic reflection, rather than merely by the degradation and ultimately the separation of the monoclinic reflection. The X-ray data also suggest that the structural state of feldspars from the peripheral portions of the pluton has been modified by reheating caused by the intrusion of adjacent younger plutons.

Serpentinization of harzburgite and dunite

Electron-probe analyses by G. R. Himmelberg of three partly serpentinized harzburgites and three partly serpentinized dunites indicate that the only chemical change that took place during serpentinization was the addition of water. Plotted on an FeO–MgO–SiO_2 triangular diagram, the bulk compositions of the serpentinized harzburgites fall on the join between the olivines (Fo_{91}) and the orthopyroxenes (En_{91}). The serpentinized dunites plot close to the composition of the olivines.

Tantalum and hafnium in diabase-granophyre suites

Neutron-activation analyses for tantalum and hafnium in 25 rocks form the diabase-granophyre suites from Dillsburg, south-central Pennsylvania, and from Tasmania have been made by L. P. Greenland. The Dillsburg suite contains more than twice as much tantalum as the Tasmanian suite. The variation of tantalum parallels that of niobium, and the Nb/Ta ratios show little variation either within or between the suites. The average Nb/Ta ratio is 14.4 for the Dillsburg suite and 13.5 for the Tasmanian suite.

Hafnium is progressively enriched in the younger rocks of both suites. Early diabase contains 0.6 to 1 ppm Hf, and late granophyre contains 5 to 8 ppm. Hf/Zr ratios indicate that hafnium is progressively enriched relative to zirconium in younger rocks.

McClure Mountain Complex, Colorado

A detailed study of the mafic and ultramafic rocks in the McClure Mountain Complex of Precambrian or Cambrian age at Iron Mountain, Fremont County, Colo., by D. R. Shawe and R. L. Parker, has shown that the layered rocks originated through processes of fractional crystallization and crystal settling in mafic magma. "Scour and fill" structures and "crossbedding" formed by minerals of different densities that make up the layers attest to the action of currents in the magma. After consolidation the layered rocks were intruded discordantly by pyroxenite and anorthosite.

Chemical composition, mineralogy, and structure of the Iron Mountain rocks indicate they are alkalic and undersaturated with silica. Structurally and genetically they are an integral part of the McClure Mountain Complex. The mafic and ultramafic rocks contain either normative nepheline or are just saturated with silica. Mineralogically they are characterized by abundant magnesium-rich olivine and clinopyroxene of salite-augite-ferrosalite composition without exsolution lamellae, and by the absence of orthopyroxene. Most of the rocks contain the alkalic amphibole kaersutite as a late-stage mineral.

Resurgent cauldrons and ring dikes

R. L. Smith and R. A. Bailey have reviewed the existing data on resurgent cauldrons, and using the Valles caldera in north-central New Mexico as a model they recognized seven stages of volcanic, structural, and sedimentary events as defining the complete resurgent-cauldron cycle. Their synthesis shows that the uplift of the resurgent dome occurs early in the post-subsidence period and before major postsubsidence volcanism from ring fractures; hence, uplift is part of a pattern rather than just a fortuitous event. The deduced timing of events gives greater credence to earlier suggestions of doming by magma pressure on the chamber roof and to the late-stage formation of ring dikes.

Study of the Bishop Tuff, California

M. F. Sheridan, mapping the Bishop Tuff of Pleistocene age has identified two local cooling units in the vicinity of lower Owens Gorge and Rock Creek Gorge in east-central California. The upper cooling unit is lens shaped and thickness to the northwest. Only one cooling unit has been found in other parts of the ash-flow sheet, and these two cooling units may merge into one thick cooling unit to the north and west. Size analyses of volcanic particles from selected unconsolidated ash-flow deposits suggest a general decrease in grain size away from the Long Valley caldera.

Chemical equilibrium between olivine phenocrysts and basaltic groundmass

K. J. Murata has concluded that the presence or absence of chemical equilibrium between olivine phenocrysts and their basaltic host groundmass can be readily demonstrated by means of the equilibrium FeO–MgO curve for the two phases, established through a chemical study of Hawaiian lavas. This curve virtually coincides with the melting curve for the synthetic system forsterite-fayalite, worked out by Bowen and Schairer. It can be extended to other mafic minerals by means of compositional relationships between them and olivine, worked out previously by others.

Inhomogeneous composition of crystallizing melts

A. T. Anderson has recognized compositional gradients in basaltic glass adjacent to olivine and plagioclase crystals. These gradients show that silicate melts adjacent to growing crystals are depleted in the elements that are enriched in the crystals. Thus, crystallizing melts are inhomogeneous and one kind of crystal is in equilibrium with melt of different composition than another kind of crystal. This relation is important to crystal-liquid equilibrium studies of either natural or experimental systems. Studies are continuing on the fractionation of specific elements.

South Dakota pegmatite

Chemical analyses of drill cores from a relatively simple pegmatite studied by J. J. Norton near Keystone, Pennington County, show that the bulk composition of the pegmatite is about 74.0 percent SiO_2, 15.0 percent Al_2O_3, 4.6 percent K_2O, 4.5 percent Na_2O, 0.6 percent H_2O, and only 1.3 percent other constituents. The pegmatite is a steeply dipping ellipsoidal body, about 170 feet thick, consisting almost entirely of albite, perthite, quartz, and muscovite. In its abundance of Al_2O_3, (contained in part, in 14 percent of modal muscovite) it is more similar to the economically valuable zoned pegmatites than to the homogeneous pegmatites of the Black Hills. Nevertheless, the pegmatite is so slightly differentiated that the analyzed samples are nearly uniform in their content of all constituents except the alkalies. The K_2O content has a range of from 5.46 percent near the hanging wall to 2.29 percent near the footwall, accompanied by a large change in abundance of perthite but little change in muscovite. Na_2O ranges from 3.97 percent in a sample near the hanging wall to 5.62 percent in albite-rich rock near the footwall. Some of the alkalies may have been transported to the site of crystallization by a gas coexisting with the magmatic liquid of granitic composition from which most of this pegmatite crystallized. In any event, the analyses represent a stage of pegmatite development at which differentiation is just beginning to be important.

Conditions of metamorphism, Grandfather Mountain window, northwestern North Carolina

Bruce Bryant (p. C10–C16) has identified assemblages containing magnetite or both magnetite and hematite, with variable and generally high Fe_2O_3/FeO ratios, and green muscovite rich in ferric iron in progressively and retrogressively metamorphosed rocks from the Grandfather Mountain window. These relations suggest the rocks were open to oxygen during metamorphism. The metamorphism apparently took place under conditions of high shearing stress, low temperature, and high P_{H_2O}.

Upside-down metamorphic zonation in California and Oregon

M. C. Blake, Jr., and others (p. C1–C9) have determined that low-grade metamorphic rocks of the blueschist facies increase in grade upward to the sole of a great thrust fault along the eastern margin of the Coast Ranges in northern California and southwestern Oregon. The gradation is defined by three textural zones of increasing reconstitution in metagraywacke, and by two metamorphic mineral zones. Metagraywacke of textural zones 1 and 2 in the Franciscan Formation (Jurassic and Cretaceous) grades upward toward the thrust into thoroughly reconstituted rocks of textural zone 3. Pumpellyite is present in zone 1, whereas lawsonite characterizes zones 2 and 3. The blueschists probably formed in a zone of cataclasis and anomalously high water pressures under the thrust fault, rather than at extreme depth as is generally postulated for such rocks. Water in excess of that required to form pumpellyite and lawsonite was available for serpentization of ultramafic rocks emplaced in the thrust fault.

Spheroidal weathering of thermally metamorphosed limestone and dolomite

Spheroidal weathering of silicate rocks has been considered to result from differential expansion accompanying hydration and clayey alteration of silicate minerals. V. C. LaMarche, Jr. (p. C32–C37) has found that silicate-free carbonate rocks in the White Mountains of east-central California weather spheroidally in contact aureoles near intrusive bodies. Comparison of the textures of the bedrock and soil indicates that the spheroidal weathering is the result of granular disintegration of joint blocks. Selective grain-boundary corrosion during weathering probably causes this disintegration and is thought to be the result of intergranular stresses that developed on cooling, following high-temperature recrystallization. La Marche regards exfoliation as an indirect consequence of increased porosity near the margins of a weathering block.

Major Pleistocene hydrothermal eruptions at Yellowstone National Park

Two areas in Lower Geyser Basin of Yellowstone National Park were sites of major hydrothermal eruptions, probably during the recession of one of the Pinedale glaciers (late Wisconsin), according to L. J. P. Muffler and D. E. White. The Pocket Basin explosion produced a crater approximately ¼ mile wide and ½ mile long, with a rim that consists exclusively of fragments of indurated and hydrothermally altered Pleistocene sedimentary rock. The Twin Buttes area contains several hydrothermal-explosion craters, the largest of which is approximately 0.4 mile in diameter. Debris ejected from the craters mantles an area of ¾ square mile, and consists in part of material emplaced by landslides rather than by a direct air-fall mechanism. The craters were produced entirely by the flashing of superheated water to steam and from energy previously stored in near-surface rocks by the hydrothermal system; there is no evidence of any direct involvement of magma.

Opal and zeolites in Pleistocene glacial deposits of Yellowstone National Park

D. E. White and L. J. P. Muffler have studied the opal-cemented sandstone and conglomerate that form hills in Lower Geyser Basin of Yellowstone National Park. Some of these hills (Twin Buttes) rise to higher elevations than the rhyolite flows that border the basin. These sedimentary rocks are interpreted to be ice-contact (kame) deposits, tentatively of Bull Lake age (732,000 years B.P.). Zeolites (mordenite, clinoptilolite, and sporadic analcite) occur in the parts of the deposits most strongly altered by alkaline waters. The spatial association of these kame deposits with present-day hydrothermal activity and with Pleistocene hydrothermal-explosion craters suggests that the deposits were localized by subglacial thermal activity and are now preserved as resistant topographic highs owing to the opal and zeolite cement.

Hydrothermal alteration in GS–6 drill hole, Steamboat Springs, Nev.

Two patterns of hydrothermal alteration of basaltic andesite and other rocks have been recognized in GS–6 drill hole at Steamboat Springs, west-central Nevada. According to Robert Schoen and D. E. White (p. B110–B119) the rocks were first subjected to potassium metasomatism that formed K-feldspar from unstable plagioclase and celadonite from ferromagnesian minerals. Later, hydrogen metasomatism produced mixed-layer illite-montmorillonite, montmorillonite, and kaolinite with increasing intensity of alteration. These clays are irregularly distributed with depth and are probably related to reactions in which CO_2 and H_2S were involved. This second period of alteration may still be in progress.

Distribution of U and Th in metasedimentary rocks of Colorado Front Range and adjoining regions

George Phair, L. B. Jenkins, and Roosevelt Moore have determined the uranium and thorium content in 60 samples of known chemical composition, mostly aluminous metasediments. The results showed that those from the Front Range contained twice as much thorium as those of similar bulk composition from Rabbit Ears Pass in the region lying to the west. This pattern of decreasing thorium content to the west parallels a similar pattern previously observed in both Precambrian and Laramide igneous rocks. No significant regional differences in uranium content were noted.

Organic chemistry of Recent sediments from Choctawhatchee Bay, Fla.

J. G. Palacas and V. E. Swanson have analyzed 50 samples from 16 cores of Recent sediments collected in the Choctawhatchee Bay area, northwest Florida. Alkaline-soluble humic substances, determined as humic and fulvic acids, were found to make up 10 to 30 percent of the total organic matter in most samples. However, as much as 55 percent was extracted from clayey sands in one of the fresh-water lake environments. The bitumen (benzene soluble material) content ranges from 0 to 2,200 ppm and is roughly proportional to the organic-carbon content. The highest bitumen content, slightly over 1 percent of the total organic-matter content, was extracted from organic-rich muds of a brackish-water swamp. Elemental or free sulfur generally constitutes less than a few percent of the total sulfur; however, in one of the Choctawhatchee River sand samples, about 50 percent of the sulfur was found to be in the elemental state.

Preliminary semiquantitative spectrographic analyses showed significant element concentrations associated with the alkaline-soluble humic substances, with proportionately higher amounts sorbed on the fulvic acids.

Copper adsorption in peat and lignite

H. L. Ong and V. E. Swanson (r1725) report that laboratory experiments show that the maximum copper concentration in peat or lignite, by adsorption, ranges from 0.6 to 2.2 percent. Thus, if the copper content of a carbonaceous rock exceeds 2.2 percent, processes other than adsorption by the organic matter were involved, or the copper originally adsorbed by the organic matter was redistributed and concentrated. Maximum adsorption of copper by peat and lignite takes place in solutions of pH 3 to 8, a pH range common in natural waters.

Analcime in Miocene Barstow Formation, San Bernardino County, Calif.

Analcime is a common authigenic silicate mineral in rhyolitic tuffs and mudstones of the Miocene Barstow Formation in the Opal Mountain quadrangle. Optical and X-ray studies by R. A. Sheppard and A. J. Gude 3d show that the analcime is associated with clinoptilolite, phillipsite, clay minerals, and (or) potassium feldspar in the altered tuff, and with clay minerals and potassium feldspar in the mudstone. The analcime is nowhere associated with relict glass. Vitroclastic texture in analcime-rich tuff is vague or nonexistent.

The composition of analcime was determined by measurement of the unit cell. Analcime from both the tuff and the mudstone shows a similar compositional range,

$$(NaAl)_{15.4}Si_{32.6}O_{96}\cdot nH_2O \text{ to } (NaAl)_{12.6}\,Si_{35.4}O_{96}\cdot nH_2O,$$

and falls at the silica-rich end of the analcime series. The most siliceous analcime from the Barstow Formation is as siliceous as any natural analcime thus far reported.

Analcime formed during diagenesis in both the tuff and the mudstone. Petrographic evidence indicates that the analcime in the tuff did not form directly from rhyolitic glass but from an alkali-rich zeolite precursor such as clinoptilolite and phillipsite. The precursor of analcime in the mudstone is uncertain.

Peridotite dike in Green and Fayette Counties, Pa.

Preliminary studies of a peridotite dike by J. B. Roen near Stringtown and Edenborn indicate that garnets noted by earlier workers are chrome-bearing pyrope. Semiquantitative spectrographic analysis shows that chromium, copper, fluorine, molybdenum, and lead have migrated from the dike into the coked intrusion zone in the Pittsburgh coal (Pennsylvanian).

Effect of weathering on glauconite and quartz monzonite

In an outcrop of the Tertiary Aquia Greensand west of Annapolis, Md., R. G. Wolff found that the weathering of glauconite does not follow the reverse of the normally accepted formation process. Chemical, mineralogical, and morphological data indicate that weathering results in the formation of goethite pseudomorphs after glauconite. The presence of a well-disseminated white coating composed of kaolinite, and probably a mixed-layer assemblage, suggests that reprecipitation accompanies the pseudomorphic replacement.

The weathering of a conical mound of quartz monzonite, commonly known as the Woodstock Granite (Carboniferous?), near Baltimore, Md., results in the breakdown of the feldspars, primarily plagioclase, to form halloysite. The ratio of $4H_2O$·halloysite/$2H_2O$·halloysite increases with depth in the mound. Analyses of water samples obtained from two sampling points at different elevations within the mound show a higher concentration of dissolved solids at 2½ feet below the surface than at 5½ feet below the surface. These differences are attributed to the increasing cation-exchange capacity of the halloysite with depth.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

Polymorphism in omphacite

Single-crystal and powder X-ray diffraction studies by J. R. Clark and J. J. Papike (r0372) of numerous pyroxene specimens with compositions in the system $CaMgSi_2O_6 - CaFe^{+2}Si_2O_6 - CaAl(SiAl)O_6 - NaAlSi_2O_6 - NaFe^{+3}Si_2O_6$ indicate that omphacites with a composition approximating $Ca_{0.5}Na_{0.5}Mg_{0.5}Al_{0.85}Si_2O_6$ may have either an ordered $P2$ structure or a disordered $C2/c$ structure. The ordered $P2$ structure has a smaller molar volume than the disordered $C2/c$ structure, a feature that is consistent with its indicated high pressure-low temperature paragenesis. These results indicate that, at low temperature and high pressure, pyroxene crystalline solutions between diopside and jadeite show strong deviations from ideal solution behavior.

Chromite and olivine from Stillwater Complex, Montana

A study of the chemical variation in coexisting chromite and olivine in the layered chromitites of the

Stillwater Complex (Precambrian) has resulted in findings of some interest in both theoretical geochemistry and economic geology. E. D. Jackson (r0014), on the basis of previous studies of these rocks, concluded that where olivine and chromite occur together in the layers the two minerals formed as simultaneous-crystallization products in equilibrium with each other and with the Stillwater magma. This hypothesis was tested by analyzing 35 pairs of coexisting olivines and chromites and comparing the compositions with theoretical values expected on the basis of free energies of formation of end-member olivines and spinels. The observed and expected values were of the same magnitude and direction. The free-energy data were then used to calculate the crystallization temperatures of the pairs, which ranged from 950° to 1,300°C, in general decreasing from bottom to top of the chromitite sections. The potential of this method as a geothermometer for all rocks containing equilibrated olivine and spinel is being investigated. In addition, the data can be used to estimate the composition of chromite directly in the mines, given only the local stratigraphic section and the amount of olivine in the rock. This method may be applicable to the Bushveld and Great Dyke Complexes as well as the Stillwater.

Crystal chemistry of beryl

Crystal-structure studies have been carried out by H. T. Evans, Jr., and M. E. Mrose (r2099) on a pure synthetic beryl and an alkali-rich beryl from Antsirabe, Madagascar. The latter specimen has the highest cesium content (11.3 percent Cs_2O) of any known beryl. The chemical formula of the cesium beryl is $Cs_{1.0}Na_{0.4}Li_{1.7}Be_{4.3}Al_{4.1}Si_{22}O_{36}(H_2O)_{0.7}$. By subtracting the electron-density synthesis of the pure synthetic beryl from that of the alkalic beryl, indications of the type of substitutions occurring in the structure and of the material filling the channels passing through the Si_6O_{18} rings have been found. Calculations thus far completed suggest that lithium replaces aluminum, and that excess aluminum replaces beryllium.

Crystal structure and cation distribution in glaucophane

The crystal structure of the high-pressure polymorph of glaucophane, GL II, from the Tiburon peninsula, California, has been refined by J. J. Papike and J. R. Clark (r2098). A least-squares analysis of the X-ray data was used to determine the cation distribution over four crystallographically independent sites in the amphibole structure. The results demonstrate that the glaucophane-II crystal structure has a highly ordered cation distribution with (0.98 Na, 0.02 Ca) in M_4, (0.91 Al, 0.09 Fe) in M_2, (0.71 Mg, 0.29 Fe) in M_3, and (0.84 Mg, 0.16 Fe) in M_1. These results compare well with the figures obtained from the bulk chemical analysis and demonstrate that X-ray-diffraction site-occupancy refinement procedures are effective for the study of homogeneous equilibria in minerals of complex chemical compositions.

X-ray determinative curve for orthopyroxenes

An X-ray determinative curve for 12 chemically analysed orthopyroxenes, based on the $\Delta 2\theta$ of the (131) orthopyroxene–(111) lithium fluoride peaks, has been established for the composition range En_{48-85} by G. R. Himmelberg and E. D. Jackson (p. B101–B102).

Quantitative X-ray determination of dawsonite

The amount of dawsonite in oil shale can be easily determined by X-ray-diffraction methods, as noted by J. W. Smith and Charles Milton (r1853). Refinements of standard techniques were made in parallel studies by B. J. Skinner and by J. R. Dyni and R. J. Hite that make it possible to estimate the dawsonite content. Both procedures rely on the height of peaks on X-ray diffractograms which are compared with standards made from mixtures containing known percentages of pure dawsonite. However, dawsonite has a wide range of crystallinity, which affects peak heights. The most commonly used standards—synthetic dawsonite and natural African dawsonite—are less well crystallized than dawsonite from the Green River Formation (Eocene) and do not provide the best basis for comparison. Concentrates of the very fine grained Green River dawsonite, prepared by a multiple-stage heavy-liquid-separation process developed by B. M. Madsen, provide more accurate standards. The crystal-cell dimensions of the concentrates also confirm that the Green River dawsonite is more highly crystallized than African and artificial dawsonites, that its unit cell is larger along the z axis and shorter along its b and c axes, and that its total cell volume is slightly smaller.

Theoretical studies on mixed-layer minerals

E-an Zen (r2105, r1411) has studied theoretical problems related to fine-grained mixed-layer-type minerals from the viewpoint of (1) a statistical-mechanical model for mixed layering, (2) criteria for recognition of homogeneous equilibrium, and (3) characterization of mixed-layer phases by X-ray-diffraction techniques. He concludes that:

(1) For a finite one-dimensional crystal having two types of units A and B capable of different stacking sequences, and having a nonzero excess energy of mixing between them, the canonical partition function can be written as a function of two interaction energies, those between AA neighbor pairs, w_{AA}, and between

AB neighbor pairs, w_{AB}, while w_{BB} is taken as the reference zero level. The partition function takes the form

$$Q=\sum \exp-(w_{AA}n+w_{AB}m)/kT$$

where the sum is overall possible configurations, n is the number of AA neighbor pairs in a given configuration, and m is the number of AB neighbor pairs in the same configuration. The average number of AA, AB, and BB neighbor pairs, then, is given by the averaging formulas

$$\overline{N}_{AA}=-[\partial \ln Q/\partial(w_{AA}/kT)] \text{ at constant } (w_{AB}/kT),$$

and similarly for $\overline{N}_{AB}$, while $\overline{N}_{BB}$ is given by the difference

$$\overline{N}_{BB}=\overline{N}-\overline{N}_{AA}-\overline{N}_{AB}-1.$$

It should be possible to work these relations backward, so that, knowing the values of $\overline{N}_{AA}$, $\overline{N}_{BB}$, and $\overline{N}_{AB}$ as, for example, from X-ray-diffraction data, one should obtain estimates of the interaction energies between different layer types according to this finite-crystal regular-solution model.

(2) As the mixing units become large relative to the grain size, statistical fluctuations, which in normal megascopic systems may be ignored, should become increasingly important. Thus, three types of scatter may be expected: (1) in the stacking sequences, (2) in the bulk composition of individual crystals of a given total length, and (3) in the length of crystals. The scatter may be observable by physical measurements. Indications of heterogeneity of such measured properties, for example the X-ray-diffraction pattern and the index of refraction, thus may not be valid evidence for a lack of homogeneous equilibrium.

X-ray diffraction profiles of mixed-layer clay minerals having two types of layers and having finite grain sizes were modeled for the computer by Zen and Malcolm Ross. The results show the extreme sensitivity of the pattern to order-disorder of the layers. Different stacking sequences which have the same overall degree of order produce much smaller differences in X-ray profiles, and such differences probably cannot be detected in real cases. In combination with the discovery by Malcolm Ross[75] of the profound influence of grain size on X-ray profiles, the results leave the entire field of X-ray identification of fine-grained minerals, especially the clay minerals, in a state of uncertainty.

[75] Malcom Ross, in press, X-ray diffraction effects by non-ideal crystals of biotite, muscovite, montmorillonite, mixed-layer clays, graphite and periclase: Zeit. Kristallogr.

X-ray diffraction effects from nonideal minerals

A Fourier transform computer program has been developed by Malcolm Ross[75] to calculate the X-ray difraction effects expected from nonideal crystals. The program evaluates the function

$$G(\mathrm{HKL})=\sum_{n=1}^{N} f_n \exp 2\pi i\ (\mathrm{H}x_n+\mathrm{K}y_n+\mathrm{L}z_n),$$

where G(HKL) is the Fourier transform at a particular H, K, L coordinate in reciprocal space, f_n is the atomic-scattering factor of the nth atom, and x, y, z its coordinates in direct space. Diffraction profiles were calculated for biotite, muscovite, and montmorillonite crystallites 2, 3, 4, 5, 6, 8, 10, 20 and 30 layers thick, and for various models of graphite and periclase. The apparent basal spacings given by finite muscovite, montmorillonite, graphite, and periclase models deviate from the true values as the platelets become thinner. For example, the apparent (001) interplanar spacing for a mica of the composition $KAl_2(Si_3Al)O_{22}$ $(OH)_2$ is 13.77, 11.13, 11.77, 10.81, 10.61, 10.38, 10.27, and 10.03 A for crystals 2, 3, 4, 5, 6, 8, 10, and 30 layers thick, respectively. For the infinitely thick crystal, $d_{001}=10.000$ A. Particle size thus may have a profound influence on the X-ray diffraction pattern of fine-grained layer silicates and prevent correct characterization of the phases.

Diffraction profiles were also calculated for 30-layer packets of random mixed-layer muscovite-montmorillonite clays. The migration curves of the (001), (002), (003), (004), and (005) muscovite maximums and of the (001), (002), (003), (004), (005), (006), (007), and (008) montmorillonite maximums, obtained from those calculations, are in general agreement with the Hendricks-Teller formulation, although certain new details appear that give a more quantitative estimate of the diffraction effects. Diffraction profiles also give a very accurate measure of line broadening. Evaluation of the graphite profiles gives the following relationship between half-width line broadening and crystal thickness:

$$2\ (\sin\theta'-\sin\theta'')=0.90\lambda/L$$

where L is the thickness of the crystal and θ' and θ'' are, respectively, the values of θ at the high- and low-angle sides of the peak.

Crystal structure of shattuckite and planchéite

H. T. Evans, Jr., and M. E. Mrose (r0192) have solved the crystal structures of the copper silicates shattuckite, $Cu_5(SiO_3)_4(OH)_2$, and planchéite, $Cu_8(Si_4O_{11})_2(OH)_4{\cdot}H_2O$. The shattuckite structure consists of $(CuO_2)_n$ layers similar to the $Mg(OH)_2$ layers in brucite. These layers link to $(SiO_3)_n$ chains, which are nearly identical in configuration to the well-known zigzag chains in pyroxene. In addition to the $(SiO_3)_n$ chains there are ladderlike $(CuO_2)_n$ chains in the structure. The planchéite crystal structure is found to be a simple extension of the shattuckite structure in which the silicon chain is doubled along the *a*-axis to form a chain closely similar to that of amphibole. A molecule of water is inserted on the twofold axis to fill the void formed by the hexagonal rings in the amphibolelike chain.

Impact metamorphism of minerals

During studies of the crystalline ejecta material from the Ries crater, West Germany, and Bosumtwi crater, Ghana, E. C. T. Chao (r1428) found that at low to moderate shock pressures quartz showed a wide range of partial transformation from a crystalline to an amorphous phase accompanied by the development of multiple sets of shock lamellae. The mean index of refraction of partially transformed quartz ranges from 1.465 (nearly that of pure silica glass) to 1.548, that of normal quartz. Plagioclase and K–feldspar also show partial phase transition, but the development of multiple sets of shock lamellae are not widespread. At higher degrees of shock, quartz and feldspar are transformed completely into amorphous phases in the solid state. The associated mafic minerals such as biotite show either pronounced kinking or evidence of partial oxidation. At a still higher degree of shock, feldspar glass shows pronounced vesiculation, and coesite or stishovite may be found in the silica glass which was derived from quartz. Decomposition of mafic minerals also begins to occur. Specimens of crystalline rocks believed to be intensely shocked contain glasses with well-developed schlieren or flow structures. Stretched lechatelierite inclusions also occur in this glass, the composition of which reflects the bulk composition of the underlying crystalline rock in which the crater was excavated.

Computer program for calculating mineral formulas

E. D. Jackson and others (p. C23–C31) have developed a procedure for reducing mineral analyses to mineral formulas, and have programmed it in extended Algol for the Burroughs B5500 computer. Input data consist of the weight percent of oxide or halogens and, if desired, the density and cell volume, from which the computer calculates ions per formula, ratios of ions, normalized values of ions, gram-formula weight, calculated density and (or) calculated cell volume. The program is available from R. W. Bowen or any representative of the Computer Division of the Geological Survey.

Nickel-iron spherules from Aouelloul glass

E. C. T. Chao, E. J. Dwornik, and Celine Merrill have found nickel-iron spherules, ranging from less than 0.2 to 50μ in diameter and containing 1.7 to 9.0 percent Ni by weight, in glass associated with the Aouelloul crater, Mauritania, Africa. The spherules occur in discrete bands of siliceous glass enriched in dissolved iron. Their discovery is significant tangible evidence that both crater and glass originated from terrestrial impact.

Trace elements in sphalerite

Forty-two sphalerite samples collected from Mississippi Valley and Appalachian Valley zinc districts show an anomalous mercury content, in amounts ranging from 100 to 300,000 ppb, according to J. L. Jolly and A. V. Heyl. Scattered analyses of several other minerals as well as of soils and wallrocks in the eastern and central United States mineral deposits also show an anomalous mercury content. The sphalerites of central Kentucky and central Tennessee also contain notable amounts of cadmium, germanium, and gallium. The unusual concentration of these elements in the sphalerite of these two districts is a feature that distinguishes them from the sphalerites of western Kentucky and eastern Tennessee. Diagenetic sphalerites collected from concretions and sedimentary fractures in the southern part of the central Kentucky district contain very low amounts of cadmium and gallium, and are essentially free of germanium. The low values for these elements in the diagenetic sphalerites distinguishes them from the more common epigenetic sphalerites in the veins of the same district.[76]

Valleriite

The crystal structure of valleriite was solved by H. T. Evans, Jr., and Rudolph Allmann (Univ. of Marburg, West Germany), and is found to consist of an unusual layer complex with a composition close to $[FeCu_{0.9}S_2]\cdot 1.53[Mg_{0.7}Al_{0.3}(OH)_2]$. Brucitelike layers carrying a positive charge because of extensive substitution of aluminum for magnesium alternate with negatively charged very dense sulfide layers in a structure which can be defined in terms of a very large and unusual type of supercell. In this way it is shown that a hydroxide component is an essential part of the valleriite phase and that the mineral belongs to a diverse class of brucite mixed-layer species which includes

[76] J. L. Jolly and A. V. Heyl, 1965, Mercury in sphalerite from central Kentucky and central Tennessee [abs.]: Geol. Soc. America Spec. Paper 87, p. 251–252.

koenenite, sjogrenite, pyroaurite, chalcophanite, lithiophorite, chlorite, and many synthetic products.

Fairchildite and buetschliite

Fairchildite and buetschliite, two minerals found in wood-ash stones formed during forest fires, have been established conclusively by M. E. Mrose and others (r2101) as the high- and low-temperature polymorphs, respectively, of $K_2Ca(CO_3)_2$. Fairchildite is hexagonal; buetschliite is trigonal. Fairchildite was synthesized in the temperature range 704°–970°C; buetschliite, in the temperature range 593°–704°C. When exposed to the atmosphere, fairchildite converts slowly to buetschliite; conversion of buetschliite to fairchildite occurs upon heating buetschliite in a closed, but not sealed, carbon crucible at temperatures as low as 704°C. The formation of buetschliite on the outer portions of wood-ash stones containing a core of fairchildite probably occurred by the recrystallization of originally formed fairchildite in strong KOH solutions derived by the leaching of potash from charred tree trunks during rainstorms.

A new calcium rare-earth borate-carbonate

A new rare-earth mineral (calcium rare-earth borate-carbonate) has been found by O. B. Raup and others (p. C38–C41) in the marine evaporites in the Paradox Member of the Hermosa Formation of Pennsylvanian age in southeastern Utah. This is the first known occurrence of any rare-earth mineral from marine evaporites. The mineral occurs in nodules in a 6-inch zone in anhydrite which immediately overlies the potash deposit in the Cane Creek mine of the Texas Gulf Sulfur Co. near Moab, Utah. The stratiform occurrence of this mineral and its relation to the host rock indicate that it is a diagenetic mineral and is most likely the result of rare-earth elements concentrated from either sea water or the sea water – sediment system.

Supergene alteration of stibnite to stibiconite

Fine-grained alteration products of stibnite are a conspicuous feature of the mercury-bearing antimony ore at the B and B deposit near Big Creek, Idaho, according to B. F. Leonard. Ten carefully purified samples of the alteration product proved, on the basis of X-ray powder analysis, to be stibiconite, $Sb^{+3}Sb_2^{+5}(O,OH,H_2O)_7$, a common oxidation product of stibnite. All powder photographs of the material show the same interplanar spacings and relative intensities. No other alteration product of stibnite was found. The stibiconite appears to be a supergene alteration product, very likely of pre-Wisconsin age.

EXPERIMENTAL GEOCHEMISTRY

Theory of phase diagrams

E. H. Roseboom, Jr., has completed a theoretical study (see U.S. Geol. Survey, r0892, p. A151) of the possible building blocks for binary, ternary, and quaternary phase diagrams. The method also applies implicitly to systems of more than four components. His results include, for the first time, all the possible univariant features of quaternary systems and all the invariant features of ternary systems, including singular points. The topological classification of phase diagrams is simplified by the recognition of analogous variables. Basically two classes of variables are recognized: variables that must take identical values in coexisting phases at equilibrium (temperature, pressure, chemical potential, fugacity, activity) and those that will have different values (specific volume, molar entropy, composition). Thus, two-dimensional phase diagrams will be of three types: both coordinates of the first type of variable, both of the second type, or one of each. Similarly, the types of phase diagrams of any particular number of coordinate axes depend on the number of possible combinations of the two types of variables. The classification aids in recognizing topological similarities between analogous diagrams. For example, the possible arrangements of phase fields in diagrams utilizing the two sets of variables temperature-composition and pressure-composition are topologically identical.

E-an Zen has found that in a specified multisystem of $n + 3$ phases (a system of n components with a total of $n + 3$ possible phases) the ends of a univariant line, in terms of temperature and pressure or any two independent intensive variables, must come together to form a smooth loop. Each passage of the loop through an invariant point changes the level of metastability of the univariant line by 1. For a complete loop the number of invariant points and segments of the univariant line must be even and no less than 4 for a nondegenerate system. There are 3 levels of stability for each univariant line, but because univariant lines cross in the closed P–T net the actual number of metastable assemblages at a general point usually exceeds 3.

Thermochemical properties of minerals

R. A. Robie and D. R. Waldbaum (Harvard University) have completed a critical summary of all available thermodynamic data for minerals at 298°K and have computed the high-temperature thermodynamic properties of about 300 minerals (298°–2,000°K at 100° intervals). Waldbaum (r1488) completed a calorimetric study of heats of mixing for the solid solution of alkali feldspars between low albite and microcline. He also completed a crystallographic study of the volume change on mixing. The data provide a basis for the development of equations of state for the alkali feldspars.

Oxidation states of mineral systems

Motoaki Sato has developed an electrochemical method for rapid determination of oxygen fugacities of silicate and oxide mineral assemblages.[77] The method is based on measurements of the electromotive force produced between the sample and a reference gas of known oxygen fugacity on opposite sides of a doped zirconia membrane which acts as a solid electrolyte specific to oxygen. In practice, the sample is heated at a slow but continuous rate, and the electromotive force is recorded continuously as a function of temperature. Preliminary results have been obtained for samples of Hawaiian tholeiite between 900°C and 1,200°C. The logarithm of the oxygen fugacity, calculated directly from the electromotive force, is found to decrease linearly with the reciprocal of the absolute temperature. The results agree with measurements by Fudali[78] at 1,200°C using another method, and also agree with Osborn's model[79] for basalts of constant composition.

D. R. Wones and M. C. Gilbert (Carnegie Institution of Washington) have determined oxygen fugacities at equilibrium for the reaction magnetite + quartz $\rightleftharpoons$ fayalite + oxygen at the temperatures 600°C, 700°C, and 800°C using the hydrogen-diffusion apparatus designed by H. R. Shaw.[80] The results provide a basis for refinement of thermodynamic data for fayalite and permit more accurate extrapolation of oxygen fugacities for the quartz-fayalite-magnetite assemblage to lower temperatures.

H. R. Shaw has examined available data for diffusion of H_2O and hydrogen in glasses as a test of the possible importance of their relative diffusivities in controlling oxidation states in granitic intrusions. Average diffusion coefficients computed from initial slopes of sorption isotherms for H_2O in obsidian[81] are not greatly affected by differences in the vapor pressure at saturation of vapor pressures between 100 bars and 2,000 bars. The temperature dependence for diffusion of H_2O in obsidian appears to be nearly the same as that for diffusion of H_2O in silica glass at temperatures to about 1,000°C, but values of average diffusivity, at the same temperature, are about two orders of magnitude higher in obsidian than in silica glass. The diffusivity of hydrogen in silica glass has a temperature dependence similar to that of H_2O and is more than three orders of magnitude higher at the same temperature.[82] [83] The mechanism of hydrogen diffusion involves proton transfer accompanying hydroxyl formation by reduction of cations. By inference, the diffusivity of hydrogen in obsidian will be increased over that of H_2O in obsidian by an amount at least as great as the differences found in silica glass. Geologically, the implication is that hydrous granitic magmas containing ferrous iron may be oxidized and "dried" by loss of hydrogen if the potential of hydrogen is low in the intruded rocks.

Activity coefficients in electrolyte solutions

P. B. Hostetler, A. H. Truesdell, and C. L. Christ have demonstrated the use of cation- and anion-sensitive electrodes for the determination of mean-activity coefficients of geochemically important electrolytes in aqueous solutions. A new graphical method has been developed to obtain accurate values of mean-activity coefficients from electromotive-force measurements, using specific electrodes (Christ and Hostetler, p. C106–C109). The method has been applied to the determination of mean-activity coefficients of KCl in aqueous solutions at temperatures from 10°C to 50°C and molalities from 0.01 to 1.0*m*. Similar methods were used to determine dissociation constants for KSO_4^{-1} at temperatures from 10°C to 50°C. The results are in good agreement with previously published data on these systems.

Reactions of minerals with aqueous solutions

P. B. Hostetler and C. I. Christ have determined experimentally the solubility product in water at 90°C for the serpentine mineral chrysotile, ideally $Mg_3Si_2O_5(OH)_4$. Both synthetic and natural (from New Idria, Calif.) chrysotile were used as starting material and gave the same result. Measurements of pH were made within the solubility cell (constructed from the silica-free material polypropylene), and samples of solution were taken periodically to determine SiO_{2aq} and Mg^{+2}.

[77] Motoaki Sato, 1966, Electrochemical investigation of the role of oxygen in igneous and metamorphic processes: [abs.]: Am. Geophys. Union Trans., v. 47, no. 1, p. 208–209.

[78] R. F. Fudali, 1965, Oxygen fugacities of basaltic and andesitic magmas. Geochim. et Cosmochim. Acta, v. 29, p. 1063–1075.

[79] E. F. Osborn, 1959, Role of oxygen pressure in the crystallization and differentiation of basaltic magma. Am. Jour. Sci., v. 257, 609–647.

[80] H. R. Shaw, 1963, Hydrogen-water vapor mixtures—Control of hydrothermal atmospheres by hydrogen osmosis: Science, v. 139, p. 1220–1222.

[81] U.S. Geological Survey, 1965, Geological Survey Research 1965, Chapter A: U.S. Geol. Survey Prof. Paper 525–A, p. A153–A154.

[82] Gordon Hetherington and K. H. Jack, 1964, The oxidation of vitreous silica: Sheffield, England, Soc. Glass Technology, Physics and Chemistry of Glasses, v. 5, no. 5, p. 147–149.

[83] Terence Drury and J. P. Roberts, 1963, Diffusion in silica glass following reaction with tritiated water vapor: Sheffield, England, Soc. Glass Technology, Physics and Chemistry of Glasses, v. 4, no. 3, p. 79–90.

The results of the experiment are represented by the product

$$[Mg^{+2}]^3\ [SiO_{2aq}]^2\ [OH^{-1}]^6/[H_2O] = 5 \times 10^{-49},$$

where the brackets indicate activities computed from the Debye-Hückel theory.

Geochemistry of aluminum

W. L. Polzer, J. D. Hem, and H. J. Gabe (p. B128–B132) have obtained small amounts of an aluminosilicate with the chemical composition of kaolinite by adding small amounts of silicic acid to dilute solutions at 250°C, in which an aluminum hydroxide polymer with the structure of gibbsite was forming. The material was not well crystallized, but tubular and lathlike forms were identified with the electron microscope.

The polymerized aluminum hydroxide was prepared by a technique described by Hem and C. E. Roberson (r1319). The polymerization process consists of the establishment of chemical bonding between adjacent aluminum ions through pairs of hydroxide ions and is of fundamental importance in the aqueous geochemistry of aluminum.

GEOCHEMISTRY OF ORE DEPOSITS

Regional zoning of silver and antimony in galena

W. E. Hall and A. V. Heyl have found a pronounced regional zoning of the silver and antimony in galena from the Illinois-Kentucky fluorite district. The concentration of silver decreases from 1,000 ppm ($\approx$30 oz per ton) at Hicks dome to about 20 ppm at the outer margins of the district (about 25 miles southeast of Hicks dome). The Ag/Sb ratio is about 0.25 in deposits near Hicks dome and increases to about 20 at the periphery of the district. The trace-element zoning pattern probably reflects the temperature of galena deposition.

Fluid inclusions characterize "stratiform" ores

Edwin Roedder has examined primary fluid inclusions in samples from a number of Mississippi Valley-type ("stratiform") lead-zinc deposits to help understand the origin of these anomalous but economically important ores. Earlier indications that the ore solutions were concentrated brines have been reinforced by this study. Included among the deposits were Timberville, Va.; southeast Missouri lead belt (including Viburnum); east Tennessee; Pine Point, Northwest Territories, Canada; and some of the more important stratiform deposits in Europe, including Picos d'Europe (Santander, Spain); Derbyshire, England; and the large lead deposits in sandstones at Laisvall, Sweden, that are very similar to those of the southeast Missouri lead belt. Homogenization temperature determinations on most of these samples (uncorrected for pressure) range from 150°C to well over 200°C. These data, indicating strong brines and elevated temperatures at the site of deposition, effectively preclude a sedimentary-syngenetic (ocean-bottom or lagoonal) origin for these deposits, a theory of origin now widely held in Europe. They show that stratiform deposits have certain features in common, implying genetic similarities, and set this class of deposits apart from the normal base-metal hydrothermal vein-type deposit.

Two isotopic varieties of lead from stratiform ore deposits

In a review of worldwide lead isotope data pertaining to stratiform deposits of lead-zinc-barite-fluorite, R. S. Cannon and A. P. Pierce note that the "Alpine" and "Mississippi Valley" types of Phanerozoic (Paleozoic, Mesozoic, and Cenozoic) stratiform ores contain two distinct isotopic varieties of lead. One variety, which might be designated the Alpine, is extremely uniform, ordinary lead of very young model age. The other variety, the well-known Mississippi Valley J-lead, is extremely variable in isotopic composition. It seems evident that the 2 isotopic varieties of lead identify 2 genetically distinct groups of ore deposits. The evidence suggests the possibility that Alpine-type, ordinary lead originated in a homogeneous source, probably deep in the earth, whereas variable, Mississippi Valley J-lead was derived at comparatively shallow depth from heterogeneous rocks.

In geographic distribution, deposits of the J-lead type are largely restricted to North America, with the exception of deposits in Norway and Sweden such as those at Laisvall. Stratiform deposits of ordinary lead in post-Precambrian rocks are important in Africa, Europe, and Asia, but are unimportant in the western hemisphere except at Pine Point, Northwest Territories, Canada.

In terms of tons of lead produced and estimated reserves, deposits of the J-lead type have a worldwide importance twice that of the Phanerozoic stratiform deposits of ordinary lead.

Inclusion geothermometry applied to geothermal well

Edwin Roedder, working in cooperation with B. J. Skinner, has examined sphalerite crystals forming 1-mm-thick joint fillings in cores from a deep well in the Salton Sea geothermal area in Imperial County, Calif. Although small, the crystals were found to have primary inclusions adequate for salinity and thermometric study. Doubly polished plates (less than 0.3 mm thick because of the intense color from the iron content) were cut parallel to the joint surface and processed carefully to avoid development of cleavage fractures. Homogenization temperatures obtained on these inclusions were in the range of 280° to 300°C; when corrected for pressure effects, these data agree well with the known bore-hole temperatures of about 310°C for the horizon involved. The inclusion liquids have freezing temperatures of —18° to —22°C, corresponding to brine of about 20 to 25 weight percent salts. Brine of similar salinity is now being produced from the well.

Salton Sea brine rich in metals

D. E. White has made a rough calculation of the probable volume of the Salton Sea geothermal system, Imperial County, Calif., and indicates that on the order of 50 cu km of rocks is saturated with "metal-rich" saline brine. Assuming an average porosity of 10 percent, the 5 cu km of brine contains the following quantities of dissolved metals, in millions of short tons: K 100, Fe 10, Mn 8, Zn 4.3, B 2.3, Li 1.3, Pb 0.45, Cs 0.09, As 0.065, Cu 0.045, Cd 0.015, Tl 0.008, Ag 0.005, and Sn 0.0025. The brine is potentially very valuable for its potassium and heavy-metal content, its reserves of lithium equal all other previously reported domestic reserves, and its cesium content probably exceeds all other domestic reserves.

Fluorite deposited by hot dilute fluids

Edwin Roedder has examined primary fluid inclusions in fluorite samples collected by R. E. Van Alstine from deposits associated with hot-spring activity in the Browns Canyon district, Chaffee County, Colo. Homogenization of the trapped gas and liquid phases takes place at temperatures ranging from 119° to 168°C (no correction for pressure has been attempted). The freezing temperature of the fluids in the inclusions is close to that of pure water, although a few may contain as much as 1,500 ppm salts. Temperature and salinity data from these ore deposits may eventually permit a reconstruction of circulation patterns at the time of deposition.

Sulfide solubility in alteration environments

In order to relate more closely the processes of hydrothermal alteration and sulfide mineralization, J. J. Hemley has undertaken an investigation of metal-sulfide solubility in environments of wallrock alteration. The experimental environment is buffered and controlled by the K-feldspar–mica–quartz and mica–pyrophyllite–quartz hydrolysis equilibria in dilute chloride solutions. For sphalerite and galena, the solubility is appreciable, on the order of 10^{-3} to 10^{-2} moles, and is much greater than that measured in dilute alkali chloride solutions alone or in alkali chloride–alkali bisulfide solutions.

Chilean salines formed at surface temperatures

Halite, soda niter ($PaNO_3$), and thenardite (Na_2SO_4) single crystals collected by G. E. Erickson from Salar Grande and a nearby nitrate deposit in the Atacama desert, Chile, have been examined by Edwin Roedder for fluid-inclusion evidence of the environment of their formation. Samples of large halite crystals, believed to have formed from subsurface recrystallization of finer grained material, showed large possibility primary inclusions and many small secondary inclusions in planes indicating minor postcrystallization shearing. Freezing and other studies of these inclusions show that the fluids present during and following recrystallization were not simply saturated NaCl solutions, but contained significant amounts of other salts, of unknown nature. These inclusions, and primary inclusions in large crystals of soda niter and thenardite, were examined on a microscope heating stage. The small bubbles in them homogenized at temperatures up to 38°– 44°C (100°– 111°F), indicating formation at "normal" surface temperatures for the region.

Unusual rare-earth distribution in marine apatite

A study of phosphorites by Z. S. Altschuler and others (p. B1–B9) has revealed an unusual distribution of rare earths in apatites of marine origin. This distribution, or fractionation pattern, closely parallels that for rare earths in sea water, and shows, as its distinguishing characteristic, a marked depletion in cerium.

Analyses from the literature of apatite of igneous origin and the present study of subaerially precipitated apatite do not show this deficiency. These results may allow nonmarine phosphate deposits to be distinguished from those of marine origin. (See also "Phosphate" in section "Investigations of Natural Resources, Mineral Resources.")

GEOCHEMICAL DATA

A. T. Meisch has investigated the effects of closed arrays in the interpretation of covariance relationships in geochemistry and concludes that the use of ratios derived from the raw percentage data avoids some of the important effects that have been described by Chayes.[84] The principal effect of the closed array is that negative relations are forced upon some of the percentage variables regardless of the manner in which the geochemical processes that concentrated the elements were related. In a study of covariance in some

[84] Felix Chayes, 1960, On correlation between variables of constant sum: Jour Geophys. Research, v. 65, no. 12, p. 4185–4193.

geochemical data on tektites (A. T. Miesch and others, r0305) each element was expressed as a ratio with respect to SiO_2. The ratios having percentage of SiO_2 in the denominator are, in fact, simpler ratios than those of the raw percentage data because the denominators of the percentages cancel. Correlations among these ratios, unlike those among raw percentage data, are independent of the variances in the data and can reflect the actual correlations among geochemical processes without as severe restrictions. Interpretations of the ratio correlations must involve only 3 elements (the 2 elements in the ratio numerators and SiO_2), whereas interpretations of correlations among percentage data should involve all elements in the rocks. The effect of the closed array on correlations among major constituents was emphasized by Chayes. Correlations of minor constituents with major ones are also affected by closure, although the effect on correlations involving only minor constituents appears to be small.

GEOCHEMISTRY OF WATER

PRECIPITATION, SURFACE WATER, AND SUBSURFACE WATER

Controls on rainfall composition

Analysis by D. W. Fisher of chemical data from the eastern North Carolina–southeastern Virginia precipitation sampling network indicates that rainfall sulfate is derived primarily from an acidic source, whereas calcium and lesser amounts of the other common cations in rain are obtained from localized alkaline aerosols. Interaction of these two types of aerosols appears to be the principal control on rainfall pH (or bicarbonate concentration for the more alkaline samples).

Marine aerosols also provide considerable quantities of ionic material to precipitation over the area.

Acid mine drainage from Lee shaft in Northern anthracite field

In a study of the Lee shaft, Mocanaqua, Pa., T. G. Newport and H. E. Koester have found that a rapid increase in dissolved constituents at the 290-foot level was indicated by fluid-resistivity measurements and point samples collected at that depth. This rapid hydrofacies change corresponds to the point of hydrogen sulfide detection and is located near the top of the lower coal series. Conductance shows a 10-fold increase from top to bottom. Analyses at this bottom level indicate concentrations of Fe, SO_4, and volatile carbons to be 1,590 mg per l, 5,160 mg per l, and 45 mg per l, respectively. The CO_2 is replaced by CH_4.

A 40-foot zone of H_2S (290–330 feet) is represented by the lowest pH value (5.77) and a considerable drop in the ratios of Fe/SO_4 and Fe^{+2}/Fe^{+3}. This zone—which gives off a petroleum odor—changes abruptly at 330 feet to one of abundant gas, mostly volatile hydrocarbons. The interface between H_2S and hydrocarbon provides the highest pH value (6.59). When water from this zone is exposed to the atmosphere, iron is rapidly precipitated, indicating an extremely low oxidizing potential for the iron.

It is postulated that these geochemical boundaries are the result of semistagnant conditions at depth and are excellent anomalies for the study of minor elements.

Chemical variations in ground water of Red River of the North

R. W. Maclay and T. C. Winter report variations in ground-water chemistry in the glacial Lake Agassiz plain of northwestern Minnesota. These variations indicate local and regional directions of ground-water movement that are corroborated by potentiometric contours plotted in profile. Calcium-bicarbonate-type water is characteristic of ground water near its source of recharge, and sulfate-type water occurs downgradient along the flow lines. Within the eastern part of the lake plain, the sulfate-ion concentration tends to increase toward the west; however, many local variations and reversals in the direction of increasing concentration were noted. These variations in sulfate concentration may be explained partly by sulfate reduction and (or) partly by the effect of local flow systems.

Geochemistry of ground water in Yucatan Peninsula Mexico

A study of the chemical equilibrium between the carbonate minerals of the Yucatan Peninsula by B. B. Hanshaw, William Back, and Meyer Rubin indicates that a body of shallow saline water underlies the northern part of the peninsula. The wide variation in the chemistry of the water results from processes of solution of carbonate minerals and mixing with the salt water. The high Mg/Ca ratio and the high bicarbonate concentration in ground water suggest that dolomitization may be occurring on Isla Mujeres, a small island off the eastern coastline.

CHEMICAL EQUILIBRIUM AND KINETICS STUDIES

Microbial production of sulfuric acid from hydrogen sulfide

Field and laboratory investigations by G. G. Ehrlich and Robert Schoen have demonstrated the general occurrence of sulfur-oxidizing bacteria in areas with abundant H_2S in the soil atmosphere, especially in acid-leached areas near hotsprings. One hundred and ten soil samples collected at Yellowstone Park, Wyo.; Steamboat Springs, Nev.; and The Geysers, Wilbur Springs, and Sulfur Bank, Calif., were tested for the presence of sulfur-oxidizing bacteria. Isolations were made from 27 samples. Isolates were purified by enrichment-dilution techniques and are being characterized by pure culture study. Tentative identification of pure cultures indicates that the majority of the bacteria isolated belong to the genus *Thiobacillus*. Three cultures also showed a weak iron-oxidizing ability and may belong to the genus *Ferrobacillus*. Sulfur-oxidizing bacteria were found only in soil samples gathered at the surface. Although soils with temperatures as high as 47°C yielded sulfur-oxidizing bacteria, the highest temperature at which any of the pure cultures showed good growth was 37°C. Soil samples were tested for the presence of nonsulfur-oxidizing bacteria by standard plate counts. In general, the total bacterial count of the acid-leached soils was very low, and frequently, with the exception of *Thiobacillus*, only fungi were found. Enumeration of sulfur-oxidizing bacteria in the soils was not attempted.

Geochemical kinetics

A graphical technique has been developed by E. A. Jenne and Carol Lind for determining the number of reactions involved in the sorption-desorption of metallic ions by earth materials. The technique is being used, for example, to determine the approximate amount of each of the iron oxide phases present in sedimentary materials even where the iron exists as microcrystalline coatings which are not identifiable by instrumental techniques, such as X-ray diffraction.

Field study of carbonate kinetics

Work by William Back, B. B. Hanshaw, and Meyer Rubin indicates that about 10,000 years may be required for water in the limestone aquifers of central Florida to attain equilibrium with calcite. The ground water with carbon-14 concentrations indicating ages of less than about 10,000 years is generally undersaturated with respect to calcite. Water older than 10,000 years is generally supersaturated with respect to calcite; $CaCO_3$ equilibrium is apparently controlled by aragonite. More than 15,000 years of residence time in the aquifer is required for ground water to achieve equilibrium with dolomite.

Further study of the fine-grained carbonate fraction from Deep Springs Lake, Inyo County, Calif., by B. F. Jones, R. N. Clayton (University of Chicago), and R. A. Berner (Yale University) in the light of new stable-isotope and surface-reaction data suggests that a dissolution-reprecipitation mechanism most likely accounts for the formation of primary dolomite.

Metal-sorption kinetics

The sorption of cobalt on hydrous microcrystalline manganese dioxide has been found by E. A. Jenne to involve 4 distinct first-order reactions which are believed to represent 4 different sorption mechanisms. This indicates the complex nature of the sorption-desorption of the first-transition-series metals by the manganese and iron oxide coatings which are so abundant in streams and sediments.

Oxidation potentials in water

A study by Theodore Walker (University of Colorado), William Back, and R. L. Laney in the Tucson Basin, Ariz., indicates the dominant role of Eh in the formation of red beds. Preliminary results show that hematite coatings are forming down to depths of about 1,000 feet, where the Eh of water is about 500 mv and the pH is about 7.80.

The role of Eh in the occurrence of iron in municipal wells of Lafayette, La., is being studied by Larry Fayard. Preliminary results show a higher concentration of ferrous ions where the water has a lower Eh and pH.

ISOTOPE HYDROLOGY

The possibility of isotopic exchange between dissolved carbonate species in ground water and CO_3 ligands in the carbonate minerals of an aquifer could be of sufficient magnitude to invalidate the concept of radiocarbon dating of water. However, according to Irving Friedman and B. B. Hanshaw, comparison between carbon-13 values analyzed in the laboratory and carbon-13 values calculated by use of the amount of total dissolved carbonate species present at any two points in an aquifer system indicates that isotopic exchange is negligible at low temperature, even in carbonate systems. In addition, model calculations of the number of CO_3 ligands exposed in a porous limestone cube compared to the number of carbonate-species ions in the water in the cube indicates that, at the worst, exchange may make the age of water appear 10 percent older than it actually is.

Tritium analyses from ground-water wells in Florida were studied by G. L. Stewart and B. B. Hanshaw. Three wells known from radiocarbon analyses to contain young water also contained more than 15 T.U. which also indicates recent recharge. By comparison, water from 5 other wells dated as older than 12,000 years B.P. by the radiocarbon method contained no tritium. These comparisons substantiate the use of multi-isotopic measurements in hydrologic studies.

Meyer Rubin and B. B. Hanshaw collected steam from Sulphur Banks near the Hawaiian Volcanology Observatory for carbon-14 analysis to determine the extent to which the atmosphere is involved in the gaseous emanations. Both samples showed complete lack of carbon-14 activity. This may, however, be caused by large-scale exchange at elevated temperature. This could possibly be checked further by means of tritium analysis.

Deuterium analyses of brines, potable ground water, and recent rainfall from the Texas High Plains region by P. R. Stevens, Irving Friedman, and B. B. Hanshaw indicate that recent rainfall cannot be the source of highly saline springs issuing from Permian outcrop areas. Deuterium in recent rainfall averages near —1.0 percent whereas deuterium content of brines varies from —1.1 to —6.2 percent.

SALINE WATER

Brines in Great Salt Lake

Brine in Great Salt Lake, Utah, contains mostly sodium and chloride ions. During the period 1959–66, the concentration of all solids dissolved in the brine ranged from 18 to 29 percent by weight, and this variation was dependent on the annual volume of inflow and distance from sources of inflow. The chemical characteristics of four distinct types of brine found in the lake are reported by D. C. Hahl and A. H. Handy. Three of these brines result directly from either dilution by inflow or by concentration by evaporation. The fourth brine contains more sodium and fewer sulfate ions than do the other brines. The fourth brine may result from solution and precipitation of minerals on the lake bed, cation exchange between the lake sediments and ground-water discharging upward through the sediments, or anaerboic reduction of sulfate ions at the bottom of the lake. The four brine types persisted during 1965–66 through a 2-foot rise in the lake stage.

Concentration of minor elements by black shales

J. D. Vine has prepared cluster diagrams to illustrate the correlation statistics from 12 sets of minor-element analyses of black shales. These represent many different environments of organic-mud accumulation from deep- to shallow-water marine, and from brackish to hypersaline. These diagrams clearly show pronounced differences in the geochemical associations in each set that cannot be readily explained if the enriched elements, such as V, Cr, Ni, Mo, Zn, Cu, Ag, and Pb, are concentrated by absorption from normal sea water. Some black shales deposited in shallow brackish water have enrichment factors as great as those where heavy-metal concentration in sea water is not only plausible but likely. These considerations indicate that diagenetic introduction of metals in black shale may be at least as important as syngenetic absorption from sea water in explaining the content and distribution of the minor elements.

Although many heavy metals show a close association with the organic-carbon content of black shales, there is as yet no evidence to suggest that gold follows such a pattern.

Possible connate water in Eocene sandstone

G. E. Manger and W. T. Wertman (p. C192–C194) have found that cores of permeable Eocene sandstone in Karnes County, Tex., contain saline interstitial water that may be in part original connate water. Chlorinity of present-day interstitial core water seems to vary according to the original depositional environment.

Solute composition in lacustrine closed basins

Comparative analysis of recent hydrographic and hydrochemical data from the Deep Springs Lake, Calif., Abert and Summer Lakes, Oreg., and Devils Lake, N. Dak., basins by B. F. Jones and A. S. Van Denburgh has emphasized the influence of large low-gradient peripheral areas on the chemistry of saline lakes. Preliminary evidence has been summarized for interstitial storage, solute differentiation, and sedimentary-mineral genesis in these environments.

Comparison of the calcium and bromide contents of natural water over a wide range of total-solids concentration by R. S. Sanderson, D. L. Graf, and B. F. Jones has revealed a linear logarithmic relation which can be attributed to shale ultrafiltration of waters passing through sedimentary strata.

THERMAL WATER

Geysers of Steamboat Springs and general geyser mechanisms [85]

Steamboat Springs, Nev., is the third most active geyser area in the United States, after Yellowstone Park and Beowawe, Nev. More than 20 natural geysers have been identified at Steamboat Springs; most are small and inconspicuous, but eruptions to 60 feet have been described. Also, many shallow wells erupt intermittently as geysers.

Deep drilling for geothermal energy throughout the world has demonstrated that natural geysers are near-

[85] D. E. White, in press, Some principles of geyser activity, mainly from Steamboat Springs, Nevada: Am. Jour. Sci.

surface expressions of very large convection systems in which water of surface origin circulates down to surprisingly great depths—on the order of 5,000 to 10,000 feet in the deepest explored systems. Study of oxygen and hydrogen isotopes in the waters demonstrates that at least 95 percent must be of surface origin. Volcanic steam cannot account for more than one-fourth of the heat of geyser waters, and the circulating water must therefore be heated largely by thermal conduction through solid rocks. The source of the conducted heat presumably consists of volcanic masses, perhaps still molten, that are likely to be at depths of 2 to 4 miles beneath the earth's surface.

If the water circulates too rapidly through a convection system, or if the supply of heat is too small, the upward-flowing water is not hot enough to cause geyser activity. Subsurface temperatures at least as high as 150°C (302°F) and probably above 170°C (338°F) seem to be necessary. Hot water at such temperatures has more than adequate energy available for geyser eruption. Less than 5 percent of the mechanical energy available in the expanding steam could sweep the associated water upward to a height of 200 feet in a major geyser eruption.

The near-surface part of a convection system are inherently unstable because high-temperature water, with high energy but low density (because of thermal expansion at the higher temperature), is rising into near-surface water that is heavier because it has already partly cooled and contracted. Small convection cells occur wherever open spaces are interconnected or are large, as in spring pools and geyser tubes. The excess energy is thereby dissipated, and most individual spring systems are stabilized to such an extent that geyser eruptions are either infrequent or do not occur at all.

A geyser is a special type of hot spring that has channels and dimensions that are too narrow to permit convective loss of all excess energy under steady or constant conditions. Instead, the supply of energy periodically becomes so large that eruption occurs. Many different aspects of the eruption process are now understood, and help to explain the great differences in individual geysers as well as the changing behavior of a single geyser with time.

Discharge of chloride and silica, and heat flow, Yellowstone National Park

From river-discharge measurements, chloride inventories of rivers and hot springs, and underground temperatures estimated from the silica content of hot springs, R. O. Fournier, D. E. White, and A. H. Truesdell calculated the hot-spring water discharge and heat flow from most of the major hot-spring areas of Yellowstone National Park. For the area in the park east of the Continental Divide the total hot-spring flow of chloride water is 142 ± 21 cu ft per sec (4 million l per sec), containing 840,000 kcal per sec associated heat. These figures compare to 101 cu ft per sec and 190,000 kcal per sec calculated by Allen and Day, using other methods.[86]

Truesdell, Fournier, and L. J. P. Muffler made a preliminary inventory of the silica budget in Upper and Lower Geyser Basins. Silica in the Firehole River, which drains these basins, is derived both from hot-spring waters and from the weathering of rhyolite bedrock by nonthermal waters. The nonthermal (weathering) silica contribution varies from 468 g SiO_2 per sec at maximum river flow in May to 275 g SiO_2 per sec at minimum river flow in September. Hot-spring waters, independent of the season, carry to the surface about 160 g SiO_2 per sec in Upper Basin and about 450 g SiO_2 per sec in Lower Basin. Some of this silica is deposited as sinter, though most is carried away by the Firehole River. Silica deposited in Lower Basin varies seasonally from 8 to 113 g SiO_2 per sec, with a mean of 80 g SiO_2 per sec. If this rate is assumed to have been constant since the middle stade of the Pinedale Glaciation (∽12,000 years B.P.), 3×10^{13} grams of SiO_2 have been deposited in the Lower Basin. This estimate is in close agreement with an independent estimate based on detailed geologic mapping.

Thermal springs in Utah

Investigations of some chemical and thermal characteristics of major thermal springs of Utah by J. C. Mundorff indicate a very wide range in dissolved-solids concentration—from about 200 to about 45,000 ppm—for these springs. Springs having a dissolved-solids content ranging from a few hundred parts per million to a few thousand parts per million are of variable composition. Nearly all springs having concentrations exceeding about 4,000 ppm are of the sodium chloride type.

Germanium concentrations ranging from 60 to 570 $\mu g/l$ were observed in several springs along the Sevier fault in central Utah. Relatively high concentrations of lead and manganese were associated with some of the high concentrations of germanium.

Boiling temperatures have not been reported in any spring in Utah. Temperatures as high as 188°F (87°C) were measured at Abraham Hot Spring, and temper-

[86] E. T. Allen and A. L. Day, 1934, Hot springs of the Yellowstone National Park: Pacific Sci. Cong., 5th, Canada 1933, Proc., v. 3, p. 2275–2284.

atures ranging from 100° to 160°F (43°–71°C) have been measured at several springs. Preliminary inquiry indicates that steam under pressure has not been encountered in any deep drilling operations within the State of Utah.

INVESTIGATIONS AT THE HAWAIIAN VOLCANO OBSERVATORY

No Hawaiian volcano erupted during 1966, but several swarms of earthquakes have been recorded and inflation of Kilauea has proceeded all year. The earthquake swarms and the details of inflation are noteworthy.

Followup studies of December 1965 activity

In the first weeks after the Kilauea eruption of December 1965, it was thought that this event was a small one in the series of eruptions that have taken place on Kilauea's east rift zone since September 1961. As the data from precise leveling and the study of newly formed cracks became available, however, it became apparent that this event caused major structural dislocations on the south flank of Kilauea Volcano.

According to R. S. Fiske and R. Y. Koyanagi the eruption was accomplished by extensive ground cracking that extended all the way from Kane Nui o Hamo, in the east rift zone, to a point southeast of Puu Koae, 8 miles to the southwest. Hundreds of cracks and faults opened in this zone, and locally the area subsided as much as 8 feet. The area south of Kalanaokuaiki Pali was little affected by the faulting, but precise leveling along the Hilina Pali Road showed that this area was uplifted nearly 2 feet along its northern margin. This sense of seaward tilting was also substantiated by long-base tilt measurements at Kipuka Nene and Hilina Pali which showed unprecedented magnitudes of tilt toward the south. Apparently the whole block, bounded by Kalanaokuaiki Pali on the north and the Hilina Pali fault system on the south, tilted seaward during the activity of December 1965.

The chronology of events during the eruption has established an interesting relationship between the cessation of the eruption and the time of maximum structural dislocation. The eruption began at about 21^h30^m on December 24, 1965, and reached a maximum intensity within the brief span of only half an hour. At 22^h00^m, however, the tempo of earthquakes and ground cracking increased dramatically, and the rate at which lava was being erupted immediately began to diminish. In the succeeding few hours the intensity of the ground cracking and earthquake activity continued at a high rate, but the eruption ended. Moreover, much of the lava that had been erupted drained rapidly from the surface into the source fissures and other cracks. This suggests that the cracking and resulting dilation of the rift zone created new room underground at a rate greater than magma was fed into the rift zone from the summit reservoir. Eruption to the surface was therefore no longer possible, and most of the magma of December 1965 then remained underground as dikes and other intrusive bodies.

Kilauea-summit strain studies

Capability for measuring strains at Kilauea summit has been increased manyfold by augmenting the existing tiltmeter network with a system of closed level lines and horizontal-distance measurements. An excellent opportunity to test all these methods was provided during 1966 because Kilauea began inflating shortly after the December 24, 1965, flank eruption and continued inflating throughout 1966.

During the first 6 months of 1966, W. T. Kinoshita and R. S. Fiske found that the summit swelled gradually, with the center of maximum uplift about 1 km due east of Halemaumau Crater. The total uplift, relative to a point in the saddle between Kilauea and Mauna Loa, about 4 km northwest of Halemaumau Crater, was about 10 cm. During the next 3 months, the center of inflation shifted to an area about 1 km northeast of Halemaumau where the maximum uplift was about 9 cm. During the last 3 months of 1966, the center of inflation shifted to an area about 2 km south-southeast of Halemaumau where it uplifted about 12 cm. A maximum uplift of 26 cm was measured for the year at a point about 1 km east-southeast of Halemaumau.

Horizontal-distance measurements were made with a Geodimeter on a network of stations that extends from the 5,000-foot level on Mauna Loa across Kilauea Caldera to the south side of the Koae fault system. Measurements made on the net in July 1966 and again in January 1967 showed that the distance between points across the caldera increased by as much as 16 cm.

Analyses of the horizontal, vertical, and tilt changes suggests a 4-km depth to the center of pressure during the first 9 months of 1966. During the last quarter of the year, when the area of maximum uplift shifted to a point southeast of Halemaumau, the strain data suggest a 3-km depth to the center of pressure. The same general shifting of the center of pressure has been suggested by tilt data during previous periods of inflation.

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Temperature studies of Makaopuhi lava lake

Studies of Makaopuhi lava lake, formed during the eruption of March 1965, were continued during 1966 under the direction of T. L. Wright. Periodic releveling has shown that the lake surface is subsiding at a rate proportional to the square root of elapsed time.

Temperature measurements were continued in existing drill holes. In addition, two new holes (nos. 23, 24) were drilled and cased with a stainless-steel closed tube thrust into the melt to 15 feet below the crust-melt interface. After considerable trouble with contamination of thermocouples (both platinum and chrome), a temperature profile in which the bottom temperature was close to 1,140°C was obtained by using heavy-gage Cromel-Alumel wire. The thermocouple measurements were calibrated by melting GeO_2 (mp 1,115°C), Au (mp 1,063°C), and Ag (mp 961°C). By combining the two accurate profiles with the data for 1,115° from the melting of GeO_2, and isolated temperature measurements made in the melt at other times, isotherms as high as 1,150° were reconstructed as a function of depth. This is the first time this has been accomplished in the lava-lake studies. A significant conclusion from the temperature data was that the uppermost 15 feet of the Makaopuhi lake was at nearly constant temperature (1,140° ± 5°C) when the present crust began to form. This homogenization evidently reflects the many episodes of crustal foundering during and following the eruption. The eruption temperature is estimated at 1,190°C and thus the overturning cooled the top layer of melt by 50°. Temperature profiles, obtained 20 months after the eruption, still showed an inflection point at 1,135°C on a plot of temperature against depth. Below the inflection the isotherms are more closely spaced. Eventually this inflection point should disappear, and the temperature-depth plots should be regular in shape with a limiting value of 1,190°C near the central part of the lake.

Comparison of the reconstructed isothermal surfaces with modal analyses of samples of melt collected at different times yields data on the order and temperature of appearance of phases in Makaopuhi lava lake. The temperature of eruption estimated from the extrapolated temperature data agrees well with the liquidus temperature estimated from the iron/magnesium ratio of the bulk rock and the melting temperature determined in the laboratory by Tilley and others.[87]

[87] C. E. Tilley, H. S. Yoder, and J. F. Schairer, 1963, Melting relations of basalts: Carnegie Inst. Washington Yearbook 62, p. 77–84.

Differentiation of Makaopuhi lava lake is taking place by settling of olivine crystals. At a depth of 30 feet, the olivine is nearly absent from the crust, because the rate of settling nearly equals the growth rate of the crust.

Oxygen-fugacity measurements

Measurements of oxygen fugacity in the drill holes from Mahaopuhi lava lake, reported last year, were continued in 1966 (Motoaki Sato and T. L. Wright, r1734). For most of the year water condensation on the platinum leads of the oxygen probe interfered with the measurements. A reproducible profile was finally obtained using oxygen as a reference gas instead of Ni–NiO. This profile showed that the zone of high oxygen fugacity still exists between 750° and 500°C, and that oxidation of the drill core occurs within this zone.

Viscosity measurements of Makaopuhi lava lake

The field studies of viscosity in Makaopuhi lava lake made by H. R. Shaw and staff of the Volcano Observatory in 1965 (U.S. Geol. Survey, r0892, p. A159) have been further analyzed by Shaw and others (r2097). The tholeiitic lava at 1,130°C, which contains 25 percent crystals and about 5 percent vesicles, behaves as a Bingham fluid at low shear rates. The plastic viscosity is about 6,500 poises and the yield value is about 1,200 dynes cm^{-2}. Laboratory measurements using silicone fluids suggest that the plasticity is induced by the content of bubbles. The bubble-free crystal-liquid suspension has an estimated Newtonian viscosity of about 8,000 poises at 1,130°C, and the liquid fraction itself has a Newtonian viscosity of about 4,000 poises at the same temperature. The homogeneous liquid at 1,200°C (approximately the liquidus temperature) has an estimated Newtonian viscosity of 1,700 poises. It is concluded that vesicularity has an important bearing on the consistency of flowing lava. In creeping flows, vesicularity induces a high apparent stiffness, whereas in rapid flows, lava, at the same temperature, chemical composition, and proportions of phases, appears highly fluid.

ISOTOPE AND NUCLEAR STUDIES

GEOCHRONOLOGY

Age of plutonism in eastern Massachusetts

Continuing investigation of the igneous rocks around Boston, Mass., by R. E. Zartman and Geological Survey colleagues is in progress, and to date the following ages have been established:

Rock unit	Rb-Sr *whole-rock age*	K-Ar *hornblende age*
Peabody Granite	370±15 m.y. (6 samples)	371 to 403 m.y. (4 samples)
Quincy Granite	340 to 400 m.y. (9 samples)	430 to 457 m.y. (4 samples)
Cape Ann Granite	425±20 m.y. (11 samples	----------------
Andover Granite (aplite)	415±15 m.y. (3 samples)	----------------

The Peabody Granite apparently is Devonian in age with concordant Rb-Sr whole-rock and K-Ar hornblende dates. The Quincy Granite shows extensive, albeit subtle and poorly understood, disturbances of its Rb-Sr whole-rock system; the older and more closely agreeing K-Ar hornblende ages may be a truer indication of an Ordovician emplacement date. The Cape Ann Granite gives a well-defined Rb-Sr whole-rock age which is Late Ordovician or Silurian on the presently accepted time scale. Aplite and pegmatite of the Andover Granite give a Silurian Rb-Sr whole-rock age.

Stratigraphic considerations show much of the igneous activity is post-Early Cambrian (post-*Olenellus*), and the radiometric data give Late Ordovician to Devonian ages to the young alkalic plutons. It thus appears that rock units such as the extensive Salem Gabbro-Diorite and related granitic rocks, which lie stratigraphically between these time limits, are Cambrian or Ordovician in age rather than Devonian as commonly thought. A concordant Rb-Sr and K-Ar phlogopite age of 500 m.y. for the Nahant Gabbro (of former usage; now part of the Salem Gabbor-Diorite) supports this conclusion.

K-Ar ages from Boulder batholith, Montana

A coherent picture now emerges after a geochronologic study of the Boulder batholith, Montana, undertaken by J. D. Obradovich, R. I. Tilling, and M. R. Klepper. The numerous radiometric results on both the Elkhorn Mountains Volcanics and diverse plutonic phases of the batholith can be drawn into agreement with the general geologic relationships, only if it is assumed that the maximum ages obtained for any one unit provide the best approximation of its real age. Late-stage and possibly subsequent plutonic events have produced a dispersion in the ages obtained from any one unit.

K-Ar age determinations on hornblende from the lower member of the Elkhorn Mountains Volcanics provide a valid minimum of 78±0.7 m.y. for the beginning of emplacement of the Boulder batholith because the oldest elements of the batholith cut this volcanic unit. The composite batholith and its satellitic masses were emplaced and crystallized in a span of about 10 m.y. (78–68 m.y.); the overwhelming bulk ($\approx$ 90 percent) of the batholith was emplaced and crystallized in the first 6 m.y. (78–72 m.y.). However, if the ages of 78 m.y. for the Elkhorn Mountains Volcanics are minimum ages, the total time of emplacement could be extended to perhaps 13 m.y.

Age of Abrams Mica Schist, Klamath Mountains, Calif.

Rb-Sr analyses of whole-rock samples and of muscovite from the Abrams Mica Schist by M. A. Lanphere and W. P. Irwin indicate that the age of primary metamorphism is approximately 380 m.y. (Devonian). The isotopic data support the concept that the Abrams Mica Schist and the coextensive Salmon Hornblende Schist are metamorphic equivalents of unmetamorphosed Paleozoic units exposed to the east. On the basis of K-Ar mineral ages, Lanphere and Irwin suggested that the metamorphism of the schists occurred during the Carboniferous.[88] However, the age of primary metamorphism of the schists is considered to be more reliably represented by the Rb-Sr ages than by the K-Ar ages, which probably have been modified by post-Carboniferous events. The intercept values of Sr^{87}/Sr^{86} for whole-rock muscovite isochrons (0.705–0.707) seem to rule out the likelihood that the schists represent an older terrane that has been remetamorphosed. The data suggest that the schists cannot be of pre-Silurian age.

Age of igneous activity and mineralization at Bingham Canyon, Utah

A study by M. A. Lanphere of unaltered intrusive and extrusive rocks near Bingham Canyon, Utah, by the K-Ar method, indicates a period of igneous activity extending from 38.9 to 32.0 m.y. ago. The radiometric ages were determined in conjunction with the fieldwork of R. J. Roberts, E. W. Tooker, and W. J. Moore, who find geologic relationships in substantial agreement with the geochronology. The intrusive "porphyry" stocks yielding the older ages predate both sulfide mineralization and subsequent latitic volcanic rocks and their hypabyssal intrusive equivalents, whereas rhyolitic volcanic rocks southeast of the district yielding the youngest ages are stratigraphically the youngest igneous rocks in the area.

Lead-isotope ratios from eight samples of galena from the U. S. mine were determined by J. S. Stacey on a high-precision mass spectrometer. Interpretation of these data suggests that the lead was separated

[88] M. A. Lanphere and W. P. Irwin, 1965, Carboniferous isotopic age of the metamorphism of the Salmon Hornblende Schist and Abrams Mica Schist, southern Klamath Mountain, California, *in* Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525–D, p. D27–D33.

from a primary system and introduced into the crust 1,630±150 m.y. ago, where it was subsequently mixed with varied proportions of radiogenic lead of similar age. During Tertiary time the lead was remobilized and concentrated into the present ore body; biotite K-Ar dates for altered intrusive rocks associated with the ores provide an apparent age of mineralization and suggest that isotopic evolution of the lead was terminated about 36 m.y. ago.

Age of Little Elk Granite of South Dakota

A detailed radiometric-age study of the oldest rock thus far discovered in the northern Black Hills, S. Dak., has been conducted by R. E. Zartman and T. W. Stern (p. D157–D163). Five zircon separates from the Little Elk Granite are interpreted by the episodic-loss model to have originally crystallized 2,560 m.y. ago, and to have undergone disturbance during the Laramide orogeny. Twelve total-rock Rb-Sr analyses from the same unit show that extensive open-system conditions have occurred subsequent to emplacement of the granite. However, although chemical mobility can be proven for a scale greater than 1 foot, the granite as a whole appears not to have suffered net exchange with an outside environment. It has not been established if all of this element redistribution took place in Laramide time, or if some Precambrian event such as the extensive 1,700-m.y. period of intrusion and metamorphism so conspicuous in the southern Black Hills was also responsible.

Weathering effects on radiometric system

T. W. Stern, S. S. Goldich, and M. F. Newell, in cooperation with P. W. Gast of Columbia University, investigated the deleterious effects of weathering on several radiometric systems (T. W. Stern and others, r1593; S. S. Goldich and P. W. Gast, r1367).

Weathering has caused large losses of lead from the zircon in the residual clays derived from the Morton Gneiss of southwestern Minnesota, drastically reducing the Pb^{206}/U^{238} and the Pb^{207}/U^{235} ages. The Pb^{207}/Pb^{206} age probably has not been significantly affected. Loss of lead by leaching during weathering appears to be an important phenomenon which has not been adequately considered in the explanation of discordant ages of zircons. Likewise, the Rb-Sr and, to a lesser extent, the K-Ar age of biotite has been reduced. The ages are approximately 75 percent and 25 percent lower than the corresponding ages for biotite from the fresh gneiss. Thus, the effects of even incipient weathering cannot be neglected in Rb-Sr dating of biotite, and by analogy, of feldspar and whole-rock samples.

USGS interlaboratory standard muscovite, U–207

The USGS interlaboratory standard muscovite, P–207, has been distributed by M. A. Lanphere and G. B. Dalrymple (r2113) to 41 laboratories in Australia, Brazil, Canada, England, France, Germany, Holland, Italy, Japan, New Zealand, Rumania, South Africa, Switzerland, the United States, and Yugoslavia, of which 24 laboratories reported results. K-Ar analyses of P–207 have been reported by 24 laboratories, and Rb-Sr analyses have been reported by 10 laboratories. The mean values are: $Ar^{40}{}_{rad}=1.260\times10^{-9}$ moles per g; $K_2O=10.29$ percent; $Rb=9.536\times10^{-6}$ moles per g; $Sr^{87}{}_{rad}=3.209\times10^{-9}$ moles per g; and common Sr $=0.1047\times10^{-6}$ moles per g. The results indicate that for material of this type the interlaboratory precision for K-Ar ages is 2.6 percent, and for Rb-Sr ages it is 3.4 percent; the average interlaboratory precision for K-Ar ages is 1.6 percent, and for Rb-Sr ages it is 2.9 percent.

Isotope-dilution determination of five elements in reference samples G–2 and GSP–1

Concentrations of selected elements in the reference sample G–2 (granite) were determined by isotope dilution to be: Pb, 30.8 ppm; Rb, 174 ppm; Sr, 481 ppm; Th, 24.3 ppm; and U, 1.9 ppm. The Sr^{87}/Sr^{86} ratio is 0.7100 (normalize to $Sr^{86}/Sr^{88}=0.1194$). The isotopic composition of lead is: $Pb^{206}/Pb^{204}=18.518$, $Pb^{207}/Pb^{204}=15.76$, and $Pb^{208}/Pb^{204}=39.50$.

Concentrations of selected elements in the United States Geological Survey standard granodiorite GSP–1 as determined by isotope dilution are: Pb, 2.4 ppm; Rb, 268 ppm; Sr, 240 ppm; Th, 106 ppm; and U, 2.4 ppm. The Sr^{87}/Sr^{86} ratio after normalization is 0.7687. The isotopic composition of lead is: $Pb^{206}/Pb^{204}=18.077$; $Pb^{207}/Pb^{204}=15.67$; and $Pb^{208}/Pb^{204}=47.33$.

Duplicate analyses of Rb, Sr, and Pb agree to within 1 percent. Replicate analyses of U and Th show larger variations of up to ±20 percent for U and ±4–8 percent for Th. These last variations undoubtedly reflect sample inhomogeneity. The statistical treatment and a description of chemical and mass spectrometric techniques for determining lead and strontium are given by B. R. Doe and others (p. B170–B177) and by Z. E. Peterman and others (p. B181–B186).

Additional age determinations

Many age determinations are carried out by the geochronology laboratories of the Geological Survey in cooperation with Survey field geologists. The results of these investigations are reported elsewhere in this chapter and are generally listed in the index as the entry "Geochronology" under names of States or areas.

RADIOACTIVE DISEQUILIBRIUM

Uranium-series dating

In previous studies on uranium-series dating, the system was assumed to have been closed to the addition or removal of U^{238}, U^{234}, Th^{230}, and Ra^{226} after the original incorporation of uranium in the sample. Stringent criteria for a closed system are the determination of Pa^{231} and a demonstration that its growth from U^{235} gives an age concordant with that calculated for the growth of Th^{230} from U^{234}. Protactinium-231 has been determined in several aragonitic mollusk shells collected from elevated marine terraces in southern California; however, none gave concordant ages for Pa^{231}/U^{235} and Th^{230}/U^{234}. Thus, samples containing excess Pa^{231} indicate that a closed system did not exist in the shells and that, in permeating solutions, more uranium was available to the shell than was actually assimilated by the shell. An open-system model describing the migration of uranium in Pleistocene mollusk shells and in the surrounding environment was developed by J. N. Rosholt, Jr., for uranium-series dating. Analyses of U^{238}, U^{234}, Pa^{231}, and Th^{230} are required for mathematical solution of the model to determine radiometric ages extending to about 300,000 years in the past.

Determination of protactinium by neutron activation

A new method for the determination of Pa^{231}/U^{238} in samples of fossils and common crustal rocks has been developed by J. N. Rosholt, Jr., and B. J. Szabo using the technique of neutron activation. The nuclear reaction, $Pa^{231}(n,\gamma)Pa^{232} \xrightarrow[1.3\text{ days}]{\beta-} U^{232} \xrightarrow[72\text{ yrs}]{\alpha} Th^{228}$ with a thermal neutron cross section of about 340 barns, is used to produce U^{232} for subsequent comparison with the U^{238} that had been naturally incorporated in the sample. After comparison with a reference sample irradiated with the same cumulative neutron flux, the U^{232}/U^{238} ratio is proportional to the Pa^{231}/U^{238} ratio in the sample. The optimum cumulative thermal neutron flux is approximately 6×10^{18} neutrons/cm^2, producing a U^{238}/U^{232} activity ratio of 37. High-resolution alpha-spectrometer measurements are used to determine the isotopic composition of uranium chemically separated from the irradiated sample. Based on considerations of accuracy alone, the technique appears to make obsolete all previous methods used for the determination of protactinium.

Radioactive disequilibrium in basalt

The isotopic composition of uranium and thorium in five samples of basalt from historic lava flows and one sample from a Pleistocene basalt was determined by B. L. K. Somayajulu, Jr., and others (r2110). In these samples, U^{234} and U^{238} are virtually in radioactive equilibrium, but Th^{230} occurs in excess of the amount required for radioactive equilibrium with U^{234}. The data suggest that Th^{230} occurs in excess in the magma from which the historic basalts were generated.

Reference sample for determining isotopic composition of thorium

J. N. Rosholt, Jr., and others (p. B133–B136) reported a natural-occurring reference sample has been obtained that is in radioactive equilibrium and has a U/Th ratio similar to that of most crustal rocks. The rock, a porphyritic biotite granite, contains 24.1 ± 0.2 ppm U and 82.9 ± 0.9 ppm Th as determined by the technique of isotope dilution. The reference sample is used to compare the Th^{230}/Th^{232} activity ratios determined in crustal rocks and to establish the condition of radioactive equilibrium of Th^{230} to U^{238} or Th^{230} to U^{234} in these rocks, on the basis of their Th^{230}/Th^{232} and U^{238}/Th^{232} content. In the determination of Pa^{231}/U^{238} by neutron activation, the reference sample is used as an irradiated standard to establish the Pa^{231}/U^{238} ratios in rock and soil samples.

STABLE-ISOTOPE INVESTIGATIONS

Miocene dolomite of Palos Verdes Hills, Calif.

K. J. Murata and Irving Friedman have carried out O^{18}/O^{16} and C^{13}/C^{12} determinations on dolomite beds and concretionary layers in the Miocene Monterey Shale of Palos Verdes Hills. The carbon in these samples is depleted in C^{13} and suggests that carbon in these sediments was derived from bacterial decomposition of organic matter. Carbonates from other California localities yield carbon strongly enriched in C^{13}. The anomalous compositions may be explained by the reaction $C^{12}O_2 + C^{13}H_4 \rightleftarrows C^{13}O_2 + C^{12}H_4$ which will result in CO_2 enriched in C^{13}. This heavy CO_2 can react with the limestone during diagenetic dolomitization and produce a dolomite enriched in C^{13}. Dolomitization in the Monterey Shale may be an aspect of generation and migration of petroleum and associated brines. Miocene dolomites in Salinas Valley and Berkeley Hills of California, and the Coast Range of Oregon may have originated in the same way.

O^{18}/O^{16} ratios in fluid inclusions

An apparatus has been constructed in which bromine pentafluoride and small amounts of water are reacted in a nickel vessel at 150°C to liberate oxygen in 100-percent yield. The oxygen is converted to CO_2 which is analyzed by mass spectrometer for its O^{18}/O^{16} ratio. J. R. O'Neil and R. O. Rye have succeeded in obtaining precision analyses on water samples as small as 1 mg and have begun an investigation of the oxygen-isotope record in fluid inclusions. The emphasis of this study will be on problems of ore genesis. The results of the initial analyses indicate that the water in primary quartz and calcite inclusions has exchanged oxygen isotopes with the host mineral subsequent to crystallization. Therefore, the most useful data will result from analyses of fluoride and sulfide minerals where no exchange is possible.

Isotope-alteration halos

The extent of oxygen- and carbon-isotope alteration in limestone host rock has been studied in two ore deposits. At the Hill mine, southern Illinois, samples collected by D. M. Pinckney and R. O. Rye show systematic increase in δO^{18} values from 19 to 26 percent over a distance of only 25 feet away from ore. This alteration occurs in all five horizons sampled and is independent of primary textures of the limestone. δC^{13} values show no systematic relation to ore.

At the Providencia ore deposits, Zacatecas, Mexico, limestone host rock shows no large isotope halo related to intensity of mineralization. In all mines and formations studied, δO^{18} alteration is limited to a few inches and δC^{13} to a fraction of an inch from the contact with ore. The ore fluids equilibrated with the host rock only over extremely small distances even though mineralization took place at temperatures above 350°C. These results are in contrast to previous studies by A. E. J. Engel and others [89] and T. S. Lovering and others [90] that show very large isotope alteration halos related to dolomitization associated with mineralization of Gilman and Drum Mountains.

Exchange of tritium in clay minerals

Laboratory and field investigations conducted by G. L. Stewart have shown that considerable exchange occurs between tritium in tracer solutions and the structural hydroxyls of some clay minerals and soils. Samples of Davidson clay equilibrating in baths at 40°C and 60°C showed that 6 and 35 percent more tritium, respectively, had exchanged with hydroxyls than had exchanged in samples equilibrating at room temperature. The hydroxyls released from illite samples, that had been equilibrating for 6 months at room temperatures and in a dessicator with a controlled relative humidity of about 93 percent, contained about 10 percent more tritium than did adsorbed water. The rate and degree of exchange are dependent upon experimental conditions. Deuterium exchange with hydroxyls was generally observed to be less than tritium exchange.

Igneous rock and ore lead in San Juan volcanic area, Colorado

A lead-isotope study of igneous rocks and ores in the San Juan volcanic area, Colorado, has been undertaken by B. R. Doe, M. H. Delevaux, and T. A. Steven. The lead-isotope ratios for silicic volcanic rocks, basalts, and a stock underlying the San Juan volcanic area of southwestern Colorado range from 17.75 to 18.84 for Pb^{206}/Pb^{204} and from 37.1 to 38.25 for Pb^{208}/Pb^{204}. These ratio ranges are common for most igneous rocks of the Rocky Mountain provinces. The spread in isotopic composition for ores is larger than for the igneous rocks and the ores may be divided, on the basis of geologic control, into two isotopic categories.

The first occurs where geologic control closely links ore to specific igneous sources, as at Summitville in the eastern San Juans and the Marcella mine near Silverton. Here the isotope ratios of ore lead are similar to those of the associated igneous rock. The second is found for ore deposits that are not closely associated with a local igneous center and appear to have been deposited from hydrothermal solutions more remote from their source, such as at Creede. In this case, the ore is more radiogenic (for example, 19.15–19.22 for Pb^{206}/Pb^{204} at Creede and 39.0 for Pb^{208}/Pb^{204} on veins in the western part of the area) than for any igneous rocks from the San Juan Mountains or Rocky Mountain provinces analyzed so far. Although all the ores are clearly associated in time and space with the volcanic activity, the more radiogenic lead may have resulted from some contamination of the hydrothermal solution by crustal lead from Precambrian crystalline rocks or Phanerozoic (Cambrian and younger) sedimentary rocks which underlie the volcanic rocks.

Anomalously unradiogenic lead in igneous rocks

B. R. Doe has shown that leads from Mesozoic and Cenozoic igneous rocks which occur in the Rocky Mountain area underlain by old basement rock are isotopically less radiogenic and, therefore, rather distinct from those which occur along the Pacific coast where geosynclinal development may reflect new crustal addition to the continent. A study by R. E. Zartman of the isotopic composition of lead in potassium feldspars from some 1,000-m.y.-old North American igneous rocks has shown a similar phenomenon to

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

[90] T. S. Lovering, J. H. McCarthy, and Irving Friedman, 1963, Significance of O^{18}/O^{16} and C^{13}/C^{12} ratios in hydrothermally dolomitized limestones and manganese carbonate replacement ores of the Drum Mountains, Juab County, Utah: Art. 1 *in* U.S. Geol. Survey Prof. Paper 475-B, p. B1–B9.

exist for these rocks. In this case, most lead, including that from large batholithic bodies and from entirely igneous and metamorphic terranes 1,000 m.y. old, had isotopic compositions at the time of crystallization showing limited isotopic variations and yielding model ages close to its radiometric age. However, several lead samples, such as those from a rapakivi granite in the Gold Butte area of southern Nevada, a hornblende granite northwest of Mellen, Wis., and granites associated with older Labrador trough rocks near Jeannine Lake, Quebec, have distinctly unradiogenic Pb^{206}/Pb^{204} ratios. These last occurrences all involve small granitic stocks which lie in or near considerably older basement rock. Model ages calculated from the Pb^{206}/Pb^{204} ratio in these samples closely resemble the age of the old basement rock which now encloses the intrusions. It is believed that these intrusions derived their lead either by (1) a partial assimilation of the older rock from which its radiogenic component was already removed or (2) complete extraction from a low μ phase (U^{238}/Pb^{204}) of the old rock. The use of this anomalous lead to identify the presence of older rock, which is now thoroughly metamorphosed and incorporated into a younger orogenic belt, is an exciting possibility arising from this work.

Relations of oceanic basalts as indicated by lead isotopes

Mitsunobu Tatsumoto (r0517) has made an extensive lead-isotopic study of oceanic basalts in an attempt to understand better their genetic relationships. The isotopic compositions of lead and the concentrations of lead, uranium, and thorium in samples of oceanic tholeiite and alkali suites were determined. Lead of the oceanic tholeiites has a varying Pb^{206}/Pb^{204} ratio between 17.8 and 18.8, whereas leads of the alkali basalt suites from Easter Island and Guadalupe Island are very radiogenic with Pb^{206}/Pb^{204} ratios between 19.3 and 20.4. These data indicate that (1) the upper mantle source region of the tholeiite was differentiated from an original mantle material more than 1,000 m.y. ago, (2) the upper mantle is not homogeneous at the present time, (3) less than 20 m.y. was required for the crystal differentiation within the alkali suite from Easter Island, (4) no crustal contamination was involved in the source of differentiation of rocks from Easter Island; however, some crustal contamination may have affected Guadalupe Island rocks, and (5) alkali basalt may be produced from the tholeiite in the oceanic region by crustal differentiation.

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.

Partitioning coefficient of lead between K-feldspar and plagioclase

B. R. Doe and R. I. Tilling have determined the concentrations (C) of lead (Pb) in coexisting potassium feldspar (K) and plagioclase (p) by the precise isotope-dilution method for plutonic and volcanic rocks covering the geologic age range 25–2,500 m.y. The value of C^{K}_{Pb} observed in this study ranges well over a factor of 10, from 9.5 [91] to 114 ppm in a pegmatite investigated by Doe and Tilling. For comparison, the average value of C^{K}_{Pb} is 50 ppm.[92] The value of C^{K}_{Pb}/C^{p}_{Pb} is found to be greater than 1, and the values obtained thus far fall in the range 2–4.5. The most common value of C^{K}_{Pb}/C^{p}_{Pb} appears to be within about 10 percent of 2.5. Theoretically, uniform values for C^{K}_{Pb}/C^{p}_{Pb} could reflect that the distribution factor is relatively insensitive to temperature, that all the igneous rocks formed at nearly the same temperature, or that lead exchanges rapidly during cooling down of a magma to some minimum temperature. Previous data by emission spectrographic methods [93] indicated that plagioclase contains equal or greater amounts of lead than coexisting potassium feldspar in most rocks, with the exception of some pegmatites. The present data acquired by the isotope-dilution method do not support this conclusion.

Variability in isotopic composition of strontium in sea water during Paleozoic and later time

Only since the advent of mass spectrometers capable of measuring very precise isotopic compositions has it been possible to observe the small isotopic variation found in the strontium of primary carbonate in fossils. An investigation by Z. E. Peterman of several selected fossils which were thought to have lived under open-sea conditions were carried out in cooperation with C. E. Hedge and H. A. Tourtelot. Pliocene Foraminifera from the Repetto Siltstone of former usage (now Fernando Formation) have a ratio of 0.7093 (J. D. Obradovich *in* U.S. Geol. Survey, r0892, p. A161). Replicate analyses of 10 samples of *Inoceramus*, baculites, and belemnites from the Pierre Shale and Upper Cretaceous equivalents have significantly lower Sr^{87}/Sr^{86} ratios, averaging 0.7076. Other fossils analyzed and the corresponding Sr^{87}/Sr^{86} ratios are: (1) Eocene oyster (*Ostrea sp*), 0.7074; (2) Jurassic belemnites, 0.7069; (3) Pennsylvanian rugose coral, 0.7087; and

[91] G. R. Tilton, Claire Patterson, Harrison Brown, Mark Inghram, Richard Hayden, David Hess, and Esper Larson, Jr., 1955, Isotopic composition and distribution of lead, uranium, and thorium in a Precambrian granite [Ontario]: Geol. Soc. America Bull., v. 66, p. 1131-1148.

[92] Claire Patterson and Mitsunobu Tatsumoto, 1964, The significance of lead isotopes in detrital feldspar with respect to chemical diffraction within the earth's mantle: Geochim. et Cosmochim. Acta, v. 28, p. 1-22.

[93] K. S. Heier, 1962, Trace elements in feldspar—a review, *in* Christie, O. H. J., ed. The feldspar volume: Norsk Geol. Tidsskr., v. 42, p. 415-454.

(4) Ordovician limestone, 0.7084. This preliminary study suggests that (1) Ordovician and Pennsylvanian sea water did not differ appreciably in Sr isotopic composition from later Tertiary and modern sea water, and (2) during the Mesozoic and early Tertiary, the sea-water strontium was significantly less radiogenic than in Paleozoic or modern sea water.

Strontium in sea water may be assumed to be derived from three principal sources: (1) old sialic crustal material (dominantly shield areas), (2) young volcanic and plutonic rocks, and (3) carbonate rocks. Reworking of carbonate rocks would tend to buffer the Sr isotopic composition of sea water because of the high concentrations of Sr in these rocks. Large changes in the relative proportion of Sr derived from these three major sources could account for significant changes in the isotopic composition of sea water. By increasing the amount of Sr derived from young volcanic and plutonic rocks and by decreasing the amounts derived from old crustal rocks and carbonates, the Sr^{87}/Sr^{86} ratio could be lowered. Possibly these conditions were satisfied in Mesozoic time, at least in North America. Volcanism and plutonism were intense, and epicontinental seas periodically covered much of the continent—thus, the areas of old crustal rocks and Paleozoic carbonate rocks were restricted and, in a more emergent time such as the present, would be subjected to erosion.

HYDRAULIC AND HYDROLOGIC STUDIES

SURFACE WATER

Hydraulic studies of open-channel flow have contributed information on flow under ice cover, in tidal estuaries, and through bridge openings, as well as on the time of travel of contaminants in a river and the rates at which the contaminants can be expected to disperse.

Hydrologic studies have contributed information on the source, amount, and variability of annual runoff, on the amount of storage that would be required to assure a supply approaching the average annual runoff, on the characteristics of base flow, the summer temperature of water in the streams, and the amount of flow that could be diverted when the flow is greater than a specified minimum.

Use of topographic maps in computing flood profiles

L. A. Martens has compared flood profiles computed from cross sections taken from data shown on a topographic map with those computed from cross sections defined by transit-stadia surveys taken at 500-foot intervals on a 2.3-mile reach of Briar Creek in Charlotte, N. C. He reports that the average difference in profile elevation was 0.25 foot and the standard error of the differences was 0.31 foot. The topographic map was at a scale of 1:2,400 and had a contour interval of 2 feet. The profiles were computed by the step backwater method using a common set of roughness and discharge values.

Flow through bridge openings

Studies of the hydraulics of the flow of water through bridge openings not only provide information for the design of bridges but also help refine methods of determining the peak discharge by use of high-water marks upstream and downstream from a bridge opening.

Field observations made by B. L. Neely, Jr., during overbank flooding in Mississippi indicate that earthen spur dikes are effective in reducing high velocities and attendant scour at bridge abutments. Velocity measurements at bridges before and after the installation of the spur dikes confirm the findings of laboratory model studies—namely the transfer of high velocities and acceleration zones from the bridge abutments upstream to points near the end of the dikes.

At 3 stream crossings on heavily wooded flood plains in Mississippi, where bridges range in length from 345 to 490 feet, Neely and his colleagues observed that the water surface at the downstream abutments was higher than the natural or unconstricted water-surface elevations as determined from interpretation of the high-watermark profile. These findings are contrary to those from laboratory model studies and previous field observations by others.

Flow under ice cover

Standard methods of computing discharge when the stage-discharge relation is affected by ice are largely empirical and require considerable judgment in their application. In an effort to develop an analytical method, K. L. Carey (p. C200–C207) has found that a method analogous to the stage-fall-discharge method used in computing open-water discharge for streams affected by variable backwater gives a discharge measurement within 9 percent of that given by 27 discharge measurements made on the St. Croix River near Danbury, Wis., between December 1964 and January 1966. This method uses the gage height at both ends of a reach, a considerably more accurate method than the one he developed which uses the gage height at one end and a series of computations based on pipe-flow equations. From computations based on data collected in the winter of 1965–66, Carey (p. C195–C199) concludes that the computed coefficient of roughness represents the combined effect of the solid-ice undersurface and of the frazile ice which was present in variable amounts at times during the winter of 1965–66 but which was not present in 1964–65.

Transient flow in estuaries

Techniques developed for the digital simulation of transient flows in single reaches of rivers and estuaries have been extended to include transient flows in waterways of much greater lengths which are composed of many subreaches and which possess complex geometry and variable boundary conditions. Extremely flexible computer programs utilizing the implicit method and the method of characteristics for mathematical solution have been developed and are being tested by Chintu Lai (p. Z228–B232, p. D273–D280). Development of the companion computer program based upon the power-series method is being completed by R. A. Baltzer. Application of the two completed digital models to both hypothetical and actual waterway data has provided significant and valuable information regarding the character of transient flows. Recent simulation of both present and anticipated transient-flow regimens, including side-channel spillage, in Canal 111 near Everglades National Park, Fla., has amply demonstrated the ability of the digital simulation models to provide reliable and comprehensive predictive, real-time, as well as historical, data at very nominal cost.

Secondary flow circulation

Ribbons of sand observed on a clay bed of an alluvial stream are interpreted by J. K. Culbertson and V. W. Norman as evidence of secondary circulation during the period of flow. If due to helicoidal flow, the sand trails that were spaced laterally at intervals of 0.3 to 0.6 foot would indicate that the flow depth was 0.15 to 0.3 foot at the time of deposition. They suggest that variable bed shear stress between adjacent flow over bed areas of different roughness may have initiated a helicoidal flow pattern in which adjacent helicoids rotate in opposite directions about horizontal axes oriented in the direction of flow.

Dispersion in open-channel flow

Rhodamine-WT dye has been used by H. B. Fischer (p. D267–D272) as a tracer to determine the transverse mixing coefficient of a large open channel—the Atrisco Feeder Canal near Bernalillo, N. Mex. He found that when the observed coefficient of 0.11 sq ft per sec was divided by the depth and shear velocity, the resulting dimensionless coefficient of 0.24 for E_z/dU^* was in excellent agreement with previous studies at a laboratory scale.

Nobuhiro Yotsukura has developed a mathematical model for computer simulation of longitudinal diffusion of a pollutant injected into streamflow. Further work by Yotsukura based on the Fickian theory of dispersion indicates that the formula for the downstream distance required for cross-channel mixing, given previously,[94] should be revised to include a factor for the desired degree of mixing, as follows:

$$L=\frac{UW^2}{2\alpha^2K},$$

in which U, W, and K are the flow velocity, channel width, and average cross-channel mixing coefficient, respectively. The parameter, α, which has a nonlinear relation to the degree of mixing, P, is obtained from a graphical relation based on theory.

Using dispersion data previously collected[95] in six natural streams, Yotsukura found that the Fickian theory also provides a means of computing the longitudinal dispersion coefficient that is probably sufficiently accurate for the present needs of pollution abatement. The method uses routing procedure to compare field data with theoretical dispersion in order to determine a suitable value of the coefficient.

Time-of-travel measurements in streams

As the use of fluorescent dyes to measure time of travel of solutes in streams is now rather routine, the only measurements reported here are those that are unusual, either in size, methods used, application of results, or conclusions reached.

J. E. Bowie and L. R. Petri report that time-of-travel measurements were made on the Missouri River between Yankton, S. Dak., and St. Louis, Mo., in October 1966 when the stream discharge was near normal for the navigation season, and again in December 1966 after discharge had been reduced at the close of the navigation season. The 800-mile study reach, by far the longest studied by dye tracing to date, was subdivided into 10 subreaches, each of which was dosed simultaneously with rhodamine-B dye. Cumulative mean traveltimes for the study reach were approximately 298 and 380 hours for the October and December runs, respectively. In October the slowest average travel rate, 2.0 mph, was observed in the 74-mile subreach, Yankton, S. Dak., to Sioux City, Iowa, the only subreach having no channel improvement. The average rate of travel increased below Sioux City, reaching a maximum value of 3.9 mph between Omaha and Plattsmouth, Nebr., then decreasing to 2.4 mph near the mouth. In December the discharge between Yank-

[94] U.S. Geological Survey, 1965, Geological Survey Research 1965, Chapter A: U.S. Geol. Survey Prof. Paper 525–A, p. A165.

[95] R. G. Godfrey and B. J. Frederick, 1963, Dispersion in natural streams: U.S. Geol. Survey open-file rept., 75 p.

ton and Sioux City was 60 percent less than in October, and the travel rate of the dye about 25 percent less; discharge between Sioux City and Omaha was about 55 percent less, and the travel rate about 30 percent less. Below Omaha, heavy tributary inflow tended to obscure the relation of travel rate to stream discharge.

In a high-water time-of-travel measurement on the White River between Noblesville and Nora, Ind., R. E. Hoggatt has found that the velocity of the peak dye concentration was slightly lower than that obtained from a discharge-velocity relation developed for gaging stations at the two towns. This finding supports the theory that estimated traveltimes for high flows tend to be fairly accurate and may be used in conjunction with tracer studies for low and medium flows for which estimated traveltimes tend to be unreliable. Hoggatt also developed a relation between traveltime of the leading edge of dye and traveltime of the peak concentration for the upper White and East Fork White Rivers, as a means of determining leading-edge traveltime from discharge-velocity curves for high flows.

Effect of logging on stream temperatures

R. C. Williams and D. D. Harris compared water temperatures of a control stream with those of the entire 0.27 square mile of watershed of Needle Branch in the Alsea River basin near the center of the coastal Oregon area after it was cut clear of timber in June and July 1966. The average maximum daily stream temperatures for the succeeding 4 months were increased by 13°F, 11°F, 7°F, and 3°F, respectively, and the maximum of 73°F observed during the period was 12°F higher than any previously recorded temperature, in contrast to the maximum water temperature of the control stream, which was 58°F or 4°F below the maximum previously recorded. The effect on average daily minimum temperature was less pronounced and averaged only about 2°F higher than that given by correlation with the control stream. On nearby Deer Creek, where only one-quarter of the 1.17 square miles of watershed was logged by staggered cutting between June and November 1966, the average maximum daily temperature during the period June to October was only 3°F higher than that given by correlation with the control stream.

Daily fluctuation in stream temperature

For three streams in northern Nebraska, K. A. MacKichan (p. B233–B234) has found that the pattern of temperature fluctuations during the day is practically the same the year around. Although the daily range in the winter is less than half that in the summer, the minimum still occurs between 7 a.m. and 10 a.m., and the maximum between 4 p.m. and 6 p.m. He bases his conclusions on thermograph records for the months of May, July, and November which show a maximum daily fluctuation of 25°F and an average daily fluctuation of 12°F in May, 14°F in July, and 5°F in November.

Relation between average rainfall and direct runoff

By correlating the long-term average annual direct runoff (total discharge minus spring flow) of 7 streams entering Pearl Harbor, Oahu, Hawaii, with the long-term average annual precipitation on the respective drainage basins, G. T. Hirashima has found the direct runoff to be about 15 percent of the rainfall. He concludes that the direct runoff from the 90-square-mile area averages about 13 inches per year as compared to the long-term average precipitation of 83 inches per year.

Average annual runoff relations

J. B. Shjeflo uses changes in elevation of the water in a prairie pothole to measure runoff from the 340-acre closed basin draining into a natural pond in north-central North Dakota. The basin is in rolling grassland underlain by glacial till of low permeability. He found that the average annual runoff 1960–64 was 1.2 inches per year and that 1.0 inch of this was from snowmelt in the spring and only 0.2 inch from an excess of rainfall during the summer. As snowmelt runoff depends largely on winter and spring temperatures and as summer runoff depends on storm intensity, there is no correlation between precipitation and runoff. Because the pond was dry in the fall of 1964 for the first time in 25 years, he concludes that average runoff determined for the 5-year period is less than the long-term average.

Fluctuation in multiyear means of streamflow

Previous investigations of annual sequences of river discharge have appraised the extent of long-term fluctuation in multiyear means by use of the exponent k in the relation of R/S to $(N/2)^k$ in which R is the range of cumulative departure from the sample mean, S is the sample standard deviation, and N is the sequence length, in years. For a large number of sequences generated by a lag-one Markov process, N. C. Matalas has found that values of k average about 0.7, which agrees with the average found in observed sequences.

Carryover storage requirements

The amount of storage required to maintain sustained flow at high levels of development depends more on the amount of storage required to regulate yearly flow variations than on that required to regulate the within-year variations. As the allowable draft rate approaches mean flow, the total storage requirements increase so rapidly that evaporation from reservoirs precludes obtaining a draft rate equal to the mean flow. Using curves of carryover storage requirements that C. H. Hardison (r1136) developed by probability routing on annual discharge, G. O. G. Löf and C. H. Hardison (r0855) have computed the storage requirements for different levels of streamflow regulations in the 22 major regions of the conterminous United States used in a 1960 report by the Select Committee on National Water Resources, U.S. Senate, and find that at high draft rates the storage requirements are substantially higher than those previously given.

Estimating flow for succeeding 12 months

By analysis of the annual flows of the Snake River at Milner, Idaho, C. A. Thomas concludes that 250,000 acre-feet of water would be available there in 3 out of 4 years at the present stage of development, and that 1,250,000 acre-feet would be available in 50 percent of the years. His analysis is based on the fact that the flow at Milner, which is downstream from all diversions by gravity, is considered to be surplus to present needs. During the 25 percent of the years when volume is less than 250,000 acre-feet, flow comes principally from return flows below American Falls Reservoir.

Effect of glacial geology on streamflow

By using the median annual 7-day low flow as an index, F. T. Hidaka finds that the highest low-flow yield in the Puget Sound area of Washington is from the Baker River, a glacial stream tributary to the Skagit River. The low-flow index of 2.75 cfs per sq mi for this stream that drains a basin of 211 square miles contrasts sharply with the 0.03 to 0.40 cfs per sq mi for smaller streams draining the low-lying region adjacent to Puget Sound. He attributes the differences in the unit yields of these low-lying streams to differences in geologic materials in the basins.

Estimates of summer base flow

Despite a rather poor relation between monthly precipitation and corresponding increase in base flow on the Potomac River, R. L. Hanson (p. C212–C215) has found that by using such a relation in conjunction with base flow and base-flow recession rates, reasonable estimates of summer base flow can be made for subsequent 1- to 4-month periods. He attributes the lack of correlation to variations in monthly evapotranspiration rates and variations in ground-water conditions.

Base-flow component of streamflow

Knowledge of the magnitude and characteristics of the base-flow and direct-runoff components of total flow of a stream may become increasingly important to basin planning because (1) structures for detention of runoff from small drainage areas have greater potential effect on direct runoff than on base flow, and (2) the potential effect of ground-water withdrawal is to reduce base flow rather than direct runoff. In a study of runoff at 84 long-term stream-gaging stations in Kansas, L. W. Furness and M. W. Busby (p. C208–C211) have found that the base flow to be expected each month of the year can be estimated reasonably well by correlation with six physical and hydrologic characteristics of a stream basin and that correlations based on current-meter measurements at times of base flow increase the reliability of the estimates.

Potential high-water diversion

If diversion from a stream is to be allowed only when the flow in the stream exceeds a given minimum, the potential amount of diversion above this minimum flow becomes a crucial factor in designing diversion and storage facilities. By using duration tables of daily discharge that show the number of days in each class each year, M. R. Collings reports that a frequency analysis of such potential diversion can be made. The relatively simple procedure involves using the duration-table data to calculate the volume of flow each year for days with discharge above selected minimum flows. By using duration curves of daily discharge of streams in New Jersey, E. G. Miller (p. C216–C218) has computed flow-volume curves to show the percentage of volume that occurred at discharges greater than those indicated by the ordinate scale on the graph.

GROUND WATER

Ground-water studies in the Geological Survey range from simple manual operations to sophisticated research procedures. Manual operations can be steel-tape depth-to-water measurement in a well, a piezometer-orifice measurement of the discharge of a well, or perhaps a current-meter measurement of spring discharge. Sophisticated research on the occurrence and behavior of ground water includes the physical and chemical interactions of the water with the rock particles in an aquifer, the identification of complex boundary conditions that determine the functioning of a ground-water system, and optimum-development opportunities. A complete gradation exists from one type of work to the other, and all add to our knowledge and understanding of ground-water hydrology.

Regional hydrologic and geologic investigations show the extent of major cones of depression created by heavy pumping. The significance of overlap of some of these hydraulic depressions is becoming evident as a result of some of the regional studies. Newly developed borehole geophysical techniques and better understanding of applications of geophysical methods to hydrology yield detailed information on well hydraulics, well-site geology, and regional aquifer characteristics. Hydraulic and electric analog modeling are increasingly useful in applied research in ground water. Investigation of carbonate-rock terranes is continuing at an accelerated pace because of the importance of these terranes for development of large ground-water supplies and for underground disposal of wastes.

Simulation modeling of ground-water systems

Hydraulic sand models were used by J. M. Cahill to investigate the flow patterns that may occur when salt water intrudes a coastal fresh-water aquifer. The model investigations demonstrate visually that cyclic flow takes place in the denser fluids when fresh water flows seaward over intruding ocean water. When tidal fluctuations are simulated in the model by alternately raising and lowering the level of the free body of salt water, additional mixing of the two miscible fluids occurs and more salts are transported into the fresh-water region. The fluid movement was observed by following tracer dyes that were injected into both fluids. These qualitative studies indicate that the degree of salt-water intrusion is primarily controlled by the flow of the fresh water rather than by tidal effects.

A new piezometric map, prepared by R. L. Wait as a necessary step to the development of an electric-analog model of the principal artesian aquifer (Ocala Limestone of Eocene age and associated limestone) in the coastal plain of Georgia, identifies the principal areas of recharge to and discharge from the aquifer. Recharge occurs where the limestone is at or near land surface, in the areas principally north of a southwest-trending line from Statesboro through Douglas and Bainbridge, Ga. A piezometric high around Valdosta in Lowndes County may indicate a second important area of recharge.

An electric-analog model of Muscatine Island, Iowa, shows that the effective permeability of the sands and gravels is essentially a constant with respect to the regional flow system and that the effective transmissibility varies directly with the aquifer thickness. Investigators L. L. Liedtke and R. E. Hansen report that sufficient quantitative data were available to permit modeling of the transmissibility only in terms of ratios of differences from area to area. By changing the scale constants, the magnitude of the transmissibility ratios could be changed. In subsequent analysis, concurrence with known water-table conditions was achieved when the nominal transmissibilities, which were based on pumping-test data, were varied with the aquifer thickness.

Aquifer hydraulics

C. A. Appel has developed a relation for steady linear flow in a section of a confined nonleaky aquifer having the shape of two or more partial wedges connected end to end in such a way that the thickness change is nowhere abrupt. This relation can be used in a manner similar to Darcy's law. Analysis of the formula for a partial wedge indicated that the use of the average aquifer thickness, with Darcy's law, gives estimates of flow sufficiently accurate for most applications where the ratio of the maximum to minimum thickness of the partial wedge is not very large.

Recent aquifer tests in the Pearl Harbor area indicate that ground-water flow in the vicinity of a pumped well may be turbulent in the so-called basal water systems of Hawaii. R. H. Dale has found that turbulent flow may exist as far as 200 feet away from the pumped well, but that in wells 1,000 feet away the flow appears to be laminar.

A tracer study for the purpose of determining the rate of ground-water movement in Paleozoic carbonate rocks is being conducted by D. B. Grove and R. H. Johnston near the Nevada Test Site. The tracer study utilizes paired discharging and recharging wells to obtain data on real ground-water velocities, effective porosity, and ratios of selected radionuclide-ion velocities to those of water. Prior to construction of wells for the experiment, a detailed mathematical analysis was made of the variables involved in a paired discharging-recharging well system. A Burroughs 5500 computer was used to relate the following variables: distance between wells, depth of penetration into aquifer, well discharge and recharge rates, angle between the line of wells and direction of areal flow, percentage interflow between wells, and time necessary for a stated interflow return. Optimum well spacings and depths were computed and applied in the field.

Permeability and specific-yield research

A technique to determine the ratio of horizontal to vertical permeability from aquifer-test data on a partially penetrating well has been developed by E. P. Weeks. It is somewhat simpler than one that he reported previously. A variation of the new method may also be used to determine the coefficient of storage from well-test data on partially penetrating wells.

Laboratory investigations by A. I. Johnson indicate that a centrifuge technique may provide a satisfactory method for determining the permeability for unsaturated flow in soils. Specific-yield laboratory research by Johnson has refined a moisture-tension technique whereby drainage "type curves" for 15 different textures of soils may be used to predict the approximate moisture distribution after drainage of layered water-bearing systems, thus aiding calculation of the ground water available from storage.

Borehole hydrogeophysics

Geophysical logging of petroleum wells is an older practice than logging of water wells. Although most petroleum logging techniques may be utilized in hydrology, modifications in equipment and interpretation are necessary because of basic economic and environmental differences between petroleum and ground water. If logging is to be more widely applied to ground water, the expense of equipment and services must be reduced. Fortunately, this can be accomplished because most water wells not only are shallower but also have lower temperatures and pressures than oil and gas wells.

Research on the application of borehole geophysics to ground-water hydrology is being carried out by W. S. Keys and others. Currently the following types of logs are being utilized in the evaluation of ground-water environments: electric, gamma, gamma-gamma, neutron, radioactive tracer, flowmeter, caliper, fluid resistivity, gradient and differential temperature, and recently developed continuous sonic velocity. Lightweight logging sondes and control modules, either on a vehicle-mounted 6,000-foot logger or a suitcase-mounted 500-foot logger, are operated by one man. An inexpensive magnetic-tape system has been developed and is used routinely for log recording and playback.

Borehole velocity measurements were made by L. D. Carswell in wells penetrating the Brunswick Shale (Upper Triassic) in northern New Jersey. Borehole velocity measurements in wells 300 to 400 feet deep adjacent to a perennial stream in an upland area showed downward internal flow of 6 to 20 gpm under nonpumping conditions. In pumping wells having only downward flow, borehole velocity measurements showed that all water pumped came from the upper 50 to 75 feet and that downward flow was reduced by 50 to 90 percent. Wells 400 to 500 feet deep drilled in major stream valleys either had little detectable internal flow or only slight upward internal flow. When these wells were pumped, 90 percent of the water discharged came from within 200 feet of the land surface.

Formation resistivity factors for several aquifers in Mississippi have been computed by Roy Newcome, Jr., using multiple-resistivity electric logs and chemical analyses of water. Although the values are considered preliminary because of the small number of samplings, they are useful in general predictions of water quality because the interpretations are based on analysis of many electric logs. The large number of logs makes the interpretations more meaningful than those based on relatively few logs.

Regional geohydrologic-environmental studies

Maps showing the percentage of sand and the maximum thickness of sand units of the Cockfield and Yegua Formations, prepared by J. N. Payne, show the formations to be a delta–fluvial plain complex deposited by an ancestral Mississippi River system in Eocene time. Well-developed offshore bars were formed at the mouths of distributaries and parallel to the postulated shoreline in downdip interstream areas. Massive sand bodies 100 feet or more in thickness are developed along well-defined channel paths in Louisiana and Mississippi. Along these channels, coefficients of transmissibility in excess of 50,000 gpd per ft for the total sand thickness of the Cockfield Formation can be expected. Calculation of dissolved-solids content of waters in the sands of the Cockfield Formation indicates that the degree of flushing in the channel areas is higher than in the interchannel areas.

Although retention of some connate water in such sandstone is expected because of adsorption by clay minerals, G. E. Manger and W. T. Wertman suggest that in highly permeable sandstone a fraction of connate water is retained for long periods in sharp angles between sand grains. Retention is believed to depend upon the occurrence of an immobile fraction of pore water, which, even in clay-free sand packings in the Darcy range of permeability, amounts to as much as 10 to 15 percent of pore volume. This immobile fraction is stated to be localized in fine interstices between grain boundaries where it is held by capillary attraction.

Geologic findings in the drilling of a 1,500-foot test well at James Island State Park, Somerset County, Md., have given impetus to a broader study of the Upper Cretaceous and lower Tertiary aquifers occurring beneath the lower Eastern Shore of Maryland. H. J. Hansen has postulated that a gross reduction of transmissibility, due to thinning of the stratigraphic interval between the Calvert Formation (Miocene) and the Magothy Formation(Upper Cretaceous) south of the axis of the Salisbury embayment (a sedimentary basin), has increased the residence time of ground water flowing through the stratigraphic interval. The increased time of contact is presumed to have contributed to the inferior water quality that is characteristic of pre-Miocene aquifers in the southern Delmarva Peninsula.

At Cape Lisburne, Alaska, a water supply has been developed in formerly frozen alluvium beneath a small intermittent stream by modification of the thermal regime of permafrost. This modification, reported by A. J. Feulner and J. R. Williams, was a byproduct of road and reservoir construction and was brought about through (1) removal of tundra cover and the upper few feet of alluvium, (2) construction of a reservoir upstream from the development, and (3) installation of galleries downvalley from the reservoir to collect water. Similar methods may make it possible to obtain water supplies elsewhere in arctic regions where stream alluvium extends to greater depths than winter freezing.

Hydrology of crystalline-rock terranes

According to E. G. Otton, the explanation for the superior yield of wells drilled in marble in the crystalline-rock belt of Maryland appears to be that the massive marble is susceptible to both fracturing and to increased porosity by solution. In addition, in places in the Piedmont of Maryland, marble weathers to a calcite sand possessing intergranular porosity.

In parts of South Carolina marginal to the Fall Line, above-average yields have been developed in wells drilled into crystalline rock beneath a thin veneer of Coastal Plain sediments where the terrain is swampy. In addition, the swampy recharge areas may explain the presence of methane and hydrogen sulfide in the ground water.

Hydraulically transmissive fracture zones in crystalline rock at the Savannah River Plant, South Carolina, of the Atomic Energy Commission are more or less homogeneous to fluid transmission, at least over distances of less than 1,700 feet. I. W. Marine has determined the location and magnitude of fractures in seven exploration wells by packer tests of isolated sections of rock for their water-transmission characteristics and by determination of the flow of radioactive tracers from the well into fractures by means of an appropriate sensor. Several zones of water-transmitting fractures have been identified. Hydraulic coefficients determined for individual packed-off sections of rock are consistent with coefficients determined from pumping tests, which tested a much larger volume of rock.

Hydrology of carbonate-rock terranes

Robert Schneider has studied the geothermal field associated with the carbonate-rock aquifer system of central and northern Florida. By means of a thermistor probe, he has made thermal profiles of the cased parts of wells penetrating the upper part of the carbonate-rock aquifer and the overlying relatively thin mantle of mainly clastic sediments. The geothermal gradient through these strata generally is much lower than the apparent average regional gradient of 0.3°F per ft (38°C per km) that occurs below the zone of active ground-water circulation. Where significant recharge is known to occur, the gradients generally are near zero or are negative (temperature decreases with depth). On maps showing the areal temperature distribution at depths of 100 and 150 feet (30.2 and 45.4 m), "hot" regions delineate discharge areas where there is a significant upward flow component or regions where there appears to be a pronounced decrease in transmissibility. "Cold" regions, or heat sinks, generally coincide with areas of the lowest geothermal gradients and with localities of significant recharge.

B. J. Bermes' mathematical analysis of a hypothetical flow-line pattern through an artesian-aquifer system demonstrates that under certain conditions of heterogeneity and head distribution, artesian water would be oldest in areas of highest aquifer recharge. Data available on water movement and quality can be used to substantiate such a flow pattern in the limestone artesian aquifer of Volusia County in northeast Florida because laboratory tests show its water to be relatively more saturated in calcium carbonate in an area where hydraulic data (measurements of permeability and head gradient) show that limestone recharge is relatively high.

Preparation of a structure-contour map of the upper Stones River basin in central Tennessee shows that (1) rock formations dip toward the streams, (2) the streams trace or are adjacent to axes of distinct synclines which have a downstream plunge, and (3) the synclinal axes branch with the streams. This evidence suggests that near-surface structure has been produced by solution, sapping, and downwarping caused by ground-water circulation. G. K. Moore and his associates in this project believe that large amounts of ground water may be available from these synclines.

Ground-water investigations by R. V. Cushman in the Mammoth Cave area indicate that a regional hydraulic gradient extends downward from the Pennyroyal plain through the Mammoth Cave plateau to the master base-leveling stream, the Green River.

RELATIONS BETWEEN SURFACE WATER AND GROUND WATER

Estimation of ground-water flow to lake

Seeps and springs contribute an average of more than 400 cfs of inflow to upper Klamath Lake, in southern Oregon. This estimate has been made by L. L. Hubbard from an analysis of the water budget of the lake. Of this estimated inflow, which is about 15 percent of total inflow, about 10 percent occurs above the surface of the lake and 90 percent occurs below the lake level, primarily from ground-water inflow along the west side of the lake and by seepage from irrigated land at various places around the lake.

Ground-water recharge from river impoundment

O. A. Crosby made an intensive 10-day water-budget study of a 6.6-mile reach of the Souris River, which has been pooled by a low-head dam at Minot, N. Dak. The study shows a loss of about 230,000 gpd from the stream to ground water in an area where artificial methods are being used to replenish ground-water supplies. The results may not be quantitatively accurate as a long-term indicator because of changes that may have occurred in bank storage during the study period.

Observed reservoir losses associated with filling

A study of surface-water losses in the lower Nueces River in Texas by C. R. Gilbert shows the magnitude of seepage which can occur from some newly created reservoirs. The dam on the Nueces River forming Lake Corpus Christi (capacity, 302,000 acre-feet) was raised 20 feet in 1958. From 1958 to 1965 approximately 500,000 acre-feet of impounded water was lost to the newly inundated alluvium and to the contiguous aquifers. The studies also show that the capability of these aquifers to take water from the reservoir cannot be reliably computed by use of the coefficient of transmissibility. Computations based on data from observation wells around the perimeter of the lake give considerably more accurate results.

Increase in seepage estimated for planned increase in lake stage

Hydrogeologic studies have been made around the southern rim of Lake Okeechobee in south Florida to determine the increase in levee underseepage when the average lake stage is raised from about 14 feet to 16.5 feet (mean sea level). As reported by F. W. Meyer, seepage rates are greatest on the western side of the lake because of a relatively permeable aquifer at shallow depth and existence of borrow canals on both sides of the Hoover dike. The increase in seepage can range from negligible amounts to more than 6 cfs per mile. Silting of the exposed aquifers in the borrow canals decreases the seepage rates.

Quality of surface water related to ground-water flow system

According to C. E. Sloan, ground-water flow systems markedly affect the quality and, to a lesser extent, the quantity of water in prairie potholes on the Coteau du Missouri, N. Dak. Water levels in observation wells indicate that the water surface in a pothole is continuous with the phreatic surface.

Because most potholes do not overflow, seepage outflow is the principal mechanism for removal of dissolved solids concentrated by evapotranspiration. Thus, the concentration of dissolved solids in a pothole is an indirect measure of the seepage inflow-outflow relationship.

Topography influences the direction of ground-water flow, and the permeability of materials within the saturated zone affects the rate of flow. Under topographic highs, ground-water flow tends to be downward away from potholes. Because most of the poorly permeable glacial till is at a relatively high elevation on the Coteau, seepage outflow predominates and the potholes here are generally fresh. Conversely, inflow predominates in the potholes in outwash deposits that occupy low elevations on the Coteau; these ponds, which are at or below the level of the water table, are generally saline.

Hydrologic relations between lakes and ground water

Studies by W. F. Lichtler show that some lakes in central Florida may not be as effective in recharging the Floridan aquifer as has been postulated. The studies included a comparison of the fluctuation of water levels of landlocked lakes, of the water table, and of the piezometric surface of the Floridan aquifer at two test sites in a prime recharge area of Orange County, Fla. The results show that the water table near the lakes was below the lake level during most of the recent dry season. This indicates that there may be as much or possibly more recharge to the Floridan aquifer, per unit area, through the shallow aquifer surrounding the lake than through the lake bottom.

The pattern of fluctuation of the water table more closely approximates the pattern of the piezometric surface than the pattern of the lake levels, thus suggesting a better hydrologic connection between the water-table aquifer and the Floridan aquifer than between the lake and the Floridan aquifer. Accumulated silt and organic matter on the bottom of the lake may reduce infiltration.

A comparison of physical and chemical characteristics of 71 lakes in southwestern Orange County indicates that the type and degree of land development around a lake has the greatest single effect on the quality of water in the lakes in this area. Higher conductivity values in some lakes are due largely to a higher sulfate content which probably comes from sulfur materials applied to surrounding citrus groves. In other lakes, higher conductance is probably caused chiefly by pollution from nearby homes. Lower conductivity values are associated with lakes whose basins are in virtually their natural state.

Effects of changes in streamflow on water levels

Maximum ground-water-level changes in the Snake Plain aquifer in the period 1958–62 occurred in a broad trough of decline extending across the plain from Milner to Shoshone, Idaho, perpendicular to lines of regional ground-water flow. Maximum declines of about 15 and 20 feet centered around Hazelton and Shoshone, respectively. A midplain decline of about 12 feet connected the two centers. Cursory examination suggested that the trough might be caused by one event (increased irrigation pumping) which was emphasized in the trough pattern by subsurface hydraulic control. However, analysis by R. F. Norvitch of historic records shows that the decline at Shoshone can be attributed to below-average flows (1959–62) in the Little Wood River, which reflects the water available for irrigation in that area. The decline at Hazelton can be attributed to (1) cessation of winter flow in the Northside Twin Falls Canal beginning in 1961, (2) low flows in the Snake River below Milner Dam in 1959 and 1961, and (3) growth of ground-water irrigation pumping in the Milner area and upgradient from Hazelton in Jerome and Minidoka Counties. Formation of the overall trough resulted from coincidence of these conditions.

Irrigation return flow correlated with diversions

Inflow to the Snake River between Milner and King Hill, Idaho, has a high degree of correlation with diversions for irrigation onto the Snake River Plain. Studies by C. A. Thomas show that the return flow to the Snake River in the reach, which averages about 5.5 million acre-feet per year for the period of record, can be expressed with a standard error of about 5 percent by a straight-line equation $I=CD+K$, where I is the annual mean inflow, in cubic feet per second; C is a constant, averaging 0.37; D is the annual mean diversion onto the Snake River Plain, in cubic feet per second; and K is a constant, averaging 4,000 cfs. The plotting positions group by periods rather than scatter, probably because the aquifers feeding the inflow were not stabilized throughout the entire study period. Pumping from the aquifer has further altered the ground-water regimen. By dividing the period of record into the 4 periods 1919–41, 1942–53, 1954–59, and 1960–66, and drawing mean curves for the 4 periods, all the plotting positions are within about 3 percent of their respective curves. If pumping from the Snake Plain aquifer increases, the plotting positions can be expected to show less inflow for a given discharge, and new curves will be defined. The equation for the period 1960–66 is $I=0.39D+3{,}300$.

Areas of surface-water–ground-water interchange identified

R. P. Novitzki and W. A. Van Voast have developed a method for determining relationships between surface and subsurface water movement in the Yellow Medicine River Watershed unit in Minnesota. Areas of recharge or discharge to surface runoff, indicated by streamflow patterns, coincide with areas of discharge or recharge of ground water, indicated by subsurface flow patterns plotted in cross section along the general course of the river. Four distinct areas of surface-water–ground-water interchange have been located, and significant discharge from the Pleistocene glacial-drift aquifers to pre-Pleistocene bedrock aquifers has been discovered.

Duration curves of water levels used as tool

As part of a hydrologic study of the Upper Buffalo River basin, Tennessee, duration curves of water levels in wells have been prepared and used by W. J. Perry as a tool to interpret the relationship between unit declines in water level and the volume of water leaving the ground-water reservoir.

SOIL MOISTURE AND EVAPOTRANSPIRATION

Precipitation is the gross source of our water resources. The significant withdrawal of this resource is by evapotranspiration and streamflow. Soil moisture must be considered in many studies of evapotranspiration because the chemical and physical characteristics of the soil control movement and storage of the moisture and also affect the type and density of the vegetative cover. Included in Geological Survey investigations are studies of (1) movement of water through the soil, (2) evaporation from water bodies, and (3) evapotranspiration from land surfaces.

Infiltration and drainage

Jacob Rubin and C. D. Ripple have used digital computers to analyze soil-moisture movement. Numerical difference methods, which formerly had been used for analyzing only one-dimensional transient flow of water in unsaturated soils, were modified to accommodate two-dimensional transient flows. The methods have been successfully used for analyzing gravity-affected horizontal infiltration as well as soil drainage by constant-water-level ditches.

In Kansas, controlled ponding experiments by R. C. Prill have illustrated the magnitude of lateral and vertical movement of water in the loess soils. Movement of moisture below a circular ponded area having a diameter of 50 feet was measured with a neutron meter. Applications of 3½ and 7½ feet of water in the spring and fall of 1966, respectively, were made to the ponded area. Neutron measurements indicated that most of the applied water moved vertically below the ponded area. The infiltration rate of the second application was about three times greater than the first. However, the maximum lateral movement of the wetting front was approximately 7 feet for both applications.

Usable measurements of several hydrologic properties of soils and plant-soil-water relationships are being obtained by I. S. McQueen, R. F. Miller, and F. A. Branson with methods that are no more complicated than routine gravimetric soil-moisture sampling. Cellulose fiber mats (filter papers) used as moisture stress sensors in soil-moisture samples permit measurements of existing soil-moisture tensions. Successive samplings with this method define water requirements of plant communities, trace moisture movement and dissipation, measure infiltration, indicate potential infiltration or runoff, and measure moisture-stress versus plant-growth relationships.

Evaporation and seepage

The mass-transfer method[96] of computing water losses from lakes and reservoirs has been applied by W. E. Harkness in the study of a reservoir with a surface area of about 40 acres in south-central North Dakota. The dam that formed the reservoir was completed in 1962 and the water-loss study was started shortly thereafter. During the relatively short period of 4 years in which the study has been in progress, the average evaporation rate has been 35 inches per year and the average seepage rate has been 0.0024 foot per day. The seepage rate has decreased from 0.0040 foot per day in 1962 to 0.0014 foot per day in 1965, as would be expected in a new reservoir.

J. S. Meyers reports that energy-budget and mass-transfer techniques,[97] [98] as developed from observations and studies at Lake Hefner and Lake Mead, were used in 1966 for estimating the evaporation from Hungry Horse Reservoir in northwestern Montana and from Falcon Reservoir in southern Texas. The objective was to get better determinations of evaporation, particularly for short periods of time, than can be obtained from the commonly used pan. Relationships are better defined for warmer and dryer southern sites than for cooler and more humid northern sites. Problems in calibration and interpretation of readings from radiation instruments are receiving further development work.

These problems have been confirmed by H. E. Heisel and C. H. Tate in determining evaporation rates at Morse Reservoir, Hamilton County, Ind. The product of wind velocities and vapor-pressure differences does not correlate well with energy-budget evaporation rates, and there are indications of a seasonal effect.

A comparison of the results of different methods of evaporation computation made by J. F. Ficke on Pretty Lake, Ind., indicates that the energy-budget method is the best means of computing evaporation over periods of a month or longer. With proper calibration, the mass-transfer method provides economical evaporation information that is considered to be more reliable than computations by other methods during the springtime and during other periods having low evaporation rates.

The heat budget of the Pretty Lake sediment shows an average annual exchange of about 2,000 cal per cm^{-2} between the sediment and the water. In November the estimated exchange rate was 30 cal per cm^{-2} per day^{-1}, enough to affect an evaporation increase of 0.03 cm per day^{-1}.

J. F. Turner has made a comparative analysis of evaporation at two lakes in North Carolina. Roxboro Lake is located about 25 miles north of Lake Michie. Turner's analysis indicates that evaporation rates are related by the equation $Y = 1.475\ X - 1.450$, where Y is the Roxboro Lake evaporation in inches per month, and X is the Lake Michie evaporation in inches per

[96] G. E. Harbeck, 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory: U.S. Geol. Survey Prof. Paper 273-E, 101 p.

[97] U.S. Geological Survey, 1954, Water-loss investigations, Lake Hefner studies, technical report: U.S. Geol. Survey Prof. Paper 269, 158 p.

[98] G. E. Harbeck, M. A. Kohler, G. E. Koberg, and others, 1958, Water-loss investigations, Lake Mead studies: U.S. Geol. Survey Prof. Paper 298, 100 p.

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month. Differences in evaporation are attributed to windspeed and water-surface temperatures.

Computation of evapotranspiration

Phreatophyte control is one of numerous watershed-management practices which seek to increase water yield by reducing nonbeneficial evapotranspiration. A study on the flood plain of the Gila River in Arizona is being used to determine the quantity of water conserved by phreatophyte control. The study area of 6,000 acres has a vegetative cover of saltcedar (*Tamarix pentandra*) and mesquite (*Prosopis velutine*). R. C. Culler reports that preliminary estimates of annual evapotranspiration based on a water budget (inflow-outflow method) are 4 to 5 acre-feet per acre as applied to the total flood-plain area. The consumptive use by the phreatophytes at 100-percent volume density[29] (area corrected for bare ground or scattered vegetation) was in excess of 10 acre-feet per acre per year. The phreatophytes will be removed and the area seeded to grasses. The hydrologic study will continue until the revegetation is well established.

A new technique, developed by H. E. Skibitzke, of direct field measurements of evapotranspiration is being tried on the Gila Project. The technique requires measurement of the water vapor (for example, evapotranspiration) migrating across any arbitrarily selected planar surface drawn through the atmosphere at as low an altitude as possible above the stands of phreatophytes, yet closing on the earth conveniently outside the perimeter of those stands. The measurements are taken with a thermistor-type moisture-sensing element mounted in a light aircraft, which is flown just above tree-top level on traverses that will suitably define the area from which water vapor is emerging. The aircraft path is continuously tracked and recorded by a land-based radar unit, which also receives and translates into the desired record form the moisture data sensed and telemetered from the aircraft.

SEDIMENTATION

Sediment particles consisting of weathered rock and organic debris are eroded, transported, and deposited by water and therefore become of special interest to engineers and geologists who evaluate the quantity and quality of water resources, and who design for water utilization. Therefore, consideration of the natural and manmade environments, the hydraulic factors, and the economic and social implications of sedimentation processes are important. For example, the transport of sediment from a forested area may be about 10 or 20 tons per square mile per year; but when the forest is removed and subsoils exposed during urban development, the annual transport from the same area may be several thousand times greater than from the natural forest. Because the physical and biological characteristics of the stream-channel system and its flow are seriously altered by deforestation, the resultant economic and social changes may also be profound.

The following results of sedimentation investigations as related to natural or manmade environmental conditions are reported with respect to the processes of erosion and yield, transportation, and deposition.

EROSION AND YIELD

Effects of violent floods

Violent flooding of the Russian River basin, California, in December 1964 is considered by J. R. Ritter to be responsible for prolonging the high turbidity of the river through May 1965. During 1966, and years previous to 1965, the turbidity of this river decreased substantially during March.

Effects of physiographic provinces

N. L. Hawley and B. L. Jones, in a study of the Eel, Mad, Van Duzen, and Trinity River basins in northern California, have found that variations in sediment yield correlate well with the different physiographic provinces. The greatest annual suspended-sediment yields (about 8,000 tons per sq mi) are from the downstream one-third of the Eel basin in a province of deeply weathered soils and poor vegetive cover, high precipitation, many slides, and considerable soil creep into the valleys. The lowest annual yields (160 tons per square mile) are from the upper part of the Trinity basin, an area of rocks and soils on stable slopes that are resistant to erosion and slides.

K. M. Scott, J. R. Ritter, and J. M. Knott have used multiple-regression analysis to study sediment yields in Piru Creek and other basins of the San Gabriel Mountains in southern California. Yields computed by use of area and physiographic factors are substantially higher than those based on water discharge, climate, land use, and soil-erodibility factors. Marked heterogeneity in climate, lithology, and landscape maturity throughout the Transverse Range cause great differences in sediment yields.

The sediment-adjusted long-term yield of Piru Creek, which drains southward from Transverse Range, averages 840 tons per sq mi per year on the basis of 10 years of deposition in Santa Felicia Reser-

[29] J. S. Horton, T. W. Robinson, and H. R. McDonald, 1964, Guide for surveying phreatophyte vegetation: U.S. Dept. Agriculture Handb. 266, 37 p.

voir. To illustrate the variability of sediment yield from Piru Creek, a yield of 494 tons per sq mi occurred during a 7-day period in November 1965, reflecting one of the most intense storm periods in southern California's history.

Sediment from suburban highway construction

Sediment erosion and transport in an area of extensive highway construction were measured in the 4½-square-mile Scott Run basin, Fairfax County, Va., during 1961–64 by R. B. Vice, G. E. Ferguson, and H. P. Guy. On the basis of measurements made at the basin gaging station for 88 storm events, they report that midsummer flow concentrations were about double those of midwinter flow, and that the concentration and sediment yield varied with the amount of exposed area and the rapidity with which remedial measures took effect.

The estimated annual quantity of sediment eroded from the construction area of Scott Run basin was about 139 tons per acre (89,000 tons per sq mi) or about double the 70 tons per acre (45,000 tons per sq mi) measured at the gaging station. This estimate is based on particle-size comparison of core samples, sediment samples at the gaging station, and adjustments for precipitation deficiency. The sediment yield for an average storm event in construction areas was found to be about 10 times greater than for cultivated land, 200 times greater than for grass areas, and 2,000 times greater than for forest areas.

Reservoir accumulations

J. M. Knott and C. A. Dunnam report that the original storage capacities of East Park Reservoir, Colusa County, and Stony Gorge Reservoir, Glenn County, Calif., were reduced 0.07 and 0.11 percent per year by sediment accumulation prior to 1962. The annual sediment yield of Stony Creek ranged from 0.13 to 4.32 acre-feet (195 to 6,570 tons, on the basis of 70 lb per cu ft) per sq mi during the period 1957–62. An average sediment yield of 0.27 acre-feet or 410 tons per sq mi, based on the years 1957 and 1959–62, probably approximates the long-term yield of Stony Creek.

P. W. Anttilla reports that 93 percent of a total of 1,860 tons of sediment was discharged from Plum Creek reservoir No. 4, near Simpsonville, Ky., in only 6 percent of the total time between Apr. 1, 1956 and Sept. 30, 1964. Particle-size analyses of sediment discharge from this reservoir indicate that all of the sand and a substantial amount of the silt and clay entering the reservoir were trapped. The trap efficiency, computed from data of reservoir surveys and data of sediment discharge, averages 90 percent.

Sediment from landslides

Coastal rivers draining heavily forested drainage basins in southwestern Oregon during winter storms of moderate intensity carry relatively large sediment loads that range in size from boulders to clay. Preliminary observations by R. J. Janda suggest that most of the transported sediment is derived from the erosion of previously deposited valley-bottom sediments. Relatively little sediment is contributed by slope processes and minor tributaries. The time and mode of deposition of the previously deposited valley-bottom sediments are unknown. The coarseness and poor sorting of many of these deposits indicate that they were emplaced by landslides, possibly during especially severe storms. Some especially large slides have resulted in local damming of coastal streams.

Longitudinal dispersion

Equations for the moments of the longitudinal-concentration distribution of a solute undergoing dispersion in open-channel turbulent shear flow have been extended by W. W. Sayre [100] to include the case of suspended sediment as well as the sediment which drops out of suspension. A computer program was written to solve this system of equations and to compute selected statistical parameters which describe the longitudinal distribution of sediment as a function of dispersion time for a considerable variety of boundary and other input conditions. The results of the numerical solutions were found to agree relatively well with the experimental results of W. W. Sayre and F. M. Chang (r1220) for the longitudinal dispersion of silt particles and fluorescent dye and also with the results predicted for certain limiting cases by previously established theories. These results contribute significantly to a better understanding of dispersion processes in natural streams.

DEPOSITION

Effect of bed forms on flow characteristics

Methods are presented by D. B. Simons and E. V. Richardson (r0394) for predicting resistance to flow and average velocity for sand-channel streams. The methods depend on knowing the form of the bed (ripples, dunes, plane bed, or antidunes) for the given flow conditions. A relation is presented that can be used to estimate the bed form when the bed material and flow conditions are known. The report, which analyzes the data presented by H. P. Guy and others (r1171), describes many of the features of flow over sand and the interaction between variables and pro-

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[100] W. W. Sayre, 1967, Dispersion of mass in open-channel flow: Colorado State Univ., Ph.D. dissert., 192 p.

vides means of relating depositional features to environmental conditions in both recent and ancient settings.

A study by E. D. McKee, E. J. Crosby, and H. L. Berryhill, Jr., of flood-plain deposits formed along Bijou Creek, Colo., during the great floods of June 1965, indicates that the sand sheets laid down at that time reached a thickness of up to 11 feet and were composed almost entirely of horizontally laminated units. The sand sheets are typical of upper-regime flow conditions expected from these large floods, considering the slope of the valley and the great depth of flow.

Formation and movement of transverse bars

Formation and rate of movement of transverse bars in an alluvial channel having a bed form mostly of dunes and a slope of about 0.0006 have been studied by J. K. Culbertson and C. H. Scott. Sonic sounder records were used to document the development and movement of bars in a predominantly dune-bed reach. The rate of movement of several transverse bars was about 350 feet per day, regardless of bar length. The median particle size of the bed material on the dunes upstream and downstream from the bar was about 50 percent coarser than the material found on the bar (0.16 mm on the bar and 0.24 mm on the dunes.) The elevation of the bar was about the same elevation as the crests of the dunes upstream and downstream. The mechanics of formation of transverse bars is obscure; however, some form of sorting of bed material upstream from the bar may be a major causative factor.

Explanation of backset bedding

Recent experiments by A. V. Jopling and E. V. Richardson (r1184) support Davis'[101] theory of the origin of backset bedding in the fluvial glacial outwash deposits of New England, and offer a plausible explanation for the origin of backset bedding in other sedimentary formations. Theoretical and experimental work indicates that backset beds form when the flow changes from one supercritical state to another supercritical state with a lower velocity, or from a supercritical state to a subcritical state.

Orientation of structures

According to G. W. Colton (r1382), the orientation of some current-controlled structures in the Upper Devonian Catskill (red-bed) Formation of north-central Pennsylvania is incompatible with the commonly assumed source direction of that formation. Its regional thickness pattern and stratigraphic relationships indicate that the source of the Catskill sediments was to the southeast and hence that the predominant direction of sediment movement was to the northwest.

However, groove casts, rare flute casts, and other sole markings as well as plant fragments, all presumed to be parallel to the direction of current flow, are oriented largely northeast. When parting lineations are plotted, the primary as well as the secondary maximum of the parting lineations is in the northwest and southeast quadrants, and foreset beds are tightly grouped in the northwest quadrant. The most plausible interpretation of these observations is that they indicate alternation of marine currents from the northeast or southwest with nonmarine currents from the southeast.

LIMNOLOGY

Lake levels in Florida

G. H. Hughes (r1318) has used a moving average of rainfall to show that the 1966 level of Lake Jackson, a closed lake in Leon County, northern Florida, probably was the maximum for the past 80 years. Data for the lake and for ground-water wells in the area are available only for the last 15 and 32 years, respectively, but rainfall records for Tallahassee cover the past 80 years. When averaged over periods of 1 year or more, fluctuations of both lake and ground water reflect the variations in rainfall at Tallahassee. Rainfall during the last 3 years far exceeded that recorded during any like period in the last 80 years. Therefore, if the appreciable underground leakage from the lake has continued basically unchanged over the years, the present high level of the lake should rank equally with the maximum indicated for the rainfall. This inference is substantiated by the fact that fully grown oak trees near the shore now are dying owing to submergence.

A relation has been found between high lake levels and certain shoreline features (tree line of the slash pine, beach scarp, and beach ridge) of eight lakes in the Florida springs region. D. D. Knochenmus (p. C236–C241) reports that these features were exceeded by the lake level an average of only 5 percent of the time. Therefore, an estimate of past high levels of ungaged lakes can be made by using the levels of these features. The median grain diameter of the beach material also bears a relation which is consistent on all profiles with the finest material at the base of the beach scarp and with the coarsest material in the high beach ridge. This grain-size relation helps distinguish areas that have been under the influence of wave action from those that have been above the water level.

[101] W. M. Davis, 1890, Structure and origin of glacial sand plains: Geol. Soc. America Bull., v. 1, p. 195–202.

Algal studies in laboratory and field

Biological uptake of plant nutrients from the water of a recirculating laboratory stream has been studied by G. G. Ehrlich and K. V. Slack, who report that the rate of decrease in concentrations of nitrate, silicate, and phosphate was directly related to the increase in growth of attached algae in the stream. After seeding with a small quantity of algae from a natural stream, the usual pattern of microbiological growth was observel. The greatest algal growth (log phase) occurred from the 20th to the 46th day, during which time the nutrients decreased rapidly to near-zero concentrations. Little net increase in the algal biomass occurred during the long, nutrient-deficient stationary phase that followed. However, the algal mass, consisting of green, blue-green, and diatom species, was capable of assimilating large slugs of nutrients, and the rate of nutrient uptake increased with the length of time of starvation. For example, after 60 days of nutrient deficiency, added calcium nitrate was assimilated at the rate of more than 1 g per day per sq m of bottom, while sodium silicate and potassium acid phosphate were assimilated at the daily rates of 0.24 and 0.12 respectively.

Studies of phytoplankton dynamics in Pretty Lake, Lagrange County, Ind., by R. G. Lipscomb, show significant spatial variation in algal population through the seasons. Species of diatoms predominate in the late fall and during the winter beneath the ice. Species of green algae predominate in the late spring and during most of the summer, and blue-green species are dominant in the late summer and during the fall.

Reservoir destratification by air bubbling

In 1966 the thermal destratification system (a 50-hp air compressor discharging through a perforated plastic pipe) at El Capitan Reservoir, near San Diego, in southern California, maintained almost the same degree of destratification when the reservoir contained 25,000 acre-feet as it did when it contained 15,000 acre-feet in 1965. G. E. Koberg reports that the dissolved oxygen in the hypolimnion was reduced from 70 to 55 percent of saturation as a result of the increase in the volume of water in the reservoir. The hydraulic efficiency of the destratification system was computed to be 0.6 percent for the period when the maximum decrease in stability occurred. (Stability is a number that describes the degree of thermal stratification.)

Destratification experiment in Lake Cachuma, Calif.

Empirical studies of the ecological effects of destratification have been made in Lake Cachuma, Santa Barbara County, Calif. Two in-place tests were conducted in which columns of lake water, 1 sq m in cross section and 21 m deep, were enclosed in cylinders made of thin polyethylene so they could be destratified and compared with the stratified reservoir water. The cylinders were open to the atmosphere above and to the reservoir bed below.

K. V. Slack and G. G. Ehrlich (p. B235–B239), who conducted the first test, report that nearly complete thermal and chemical destratification rapidly followed air injection. Thermal stratification re-formed soon after air flow ceased, but nearly complete chemical homogeneity continued. During 4 days of intermittent air injection the dissolved-oxygen concentration increased inside the cylinder relative to the outside condition, but phytoplankton concentrations and photosynthesis decreased. This indicates that the environment after air injection was unfavorable for the existing phytoplankton species.

E. R. Hedman and S. J. Tyley (r2069) report that thermal and chemical destratification were accomplished in the second test by circulating the water with a centrifugal pump. Concentrations of silica and orthophosphate, and surface pH, decreased. Dissolved-oxygen concentration in the destratified column slowly increased to 8 ppm (the concentration in the epilimnion before circulation).

Chemical stratification in Keystone Reservoir

R. P. Orth has made a 1-year study of the chemical stratification that persisted in the Keystone Reservoir on the Arkansas and Cimarron Rivers near Tulsa, in northeastern Oklahoma. He reports that the saline Cimarron River water flowed as a density current and accumulated in the lower reaches of the reservoir beneath the fresher Arkansas River waters. Reservoir water was released only from the surface layer. The most severe stratification was observed in January, when the bottom layer ranged in salinity from 1,200 to 8,000 ppm and was warmer than the overlying fresh water. Dissolved-oxygen stratification also persisted, with concentrations near saturation in the fresh-water layer and near zero in the saline layer.

Salt exchange with lake beds

A winter loss and spring recovery of more than 25 percent of the dissolved-solids content was detected in water in 2 prairie potholes in Dickey and Stutsman Counties, in central and south-central North Dakota. J. H. Ficken (p. C228–C231) hypothesizes that freezing of the ponds results in a gradual increase in the concentration of dissolved solids in the water beneath the ice, causing increased diffusion into the bed material. As the ponds and bed material thaw in the spring, the solids diffuse back into the water over a period of a month or longer.

Summer Lake, which occupies a broad, shallow closed basin in Lake County, south-central Oregon, has regained an appreciable solute tonnage since a time of near dryness in 1962. A. S. Van Denburgh reports the following:

Year	Dissolved solids (millions tons)	Surface area (sq mi)
1963	0.52	59
1964	.71	57
1965	.95	66
1966	1.14	61

In both 1964 and 1966 the amount of dissolved salts (mostly sodium carbonate, bicarbonate, and chloride) in Summer Lake increased, even though the area inundated did not. The solute increases in those 2 years were not contributed by inflow, so it is assumed that they represent further leaching of salts from the lake bottom and from the immediately peripheral sediments

GEOMORPHOLOGY

Channel-morphology studies

Measurements made from 1964 to 1966 by M. E. Cooley indicate that arroyos cut during the past century in the Navajo Country of northeastern Arizona, northwestern New Mexico, and southeastern Utah are as much as 92 feet deep. Along some of the other major streams, the maximum depth of arroyos ranges from 31 feet along Pueblo Colorado Wash near Bidahochi Trading Post to 71 feet along Dinnebito Wash south of Howell Mesa.

Although arroyo cutting has been severe in many valleys of southwestern United States, another study by R. F. Hadley and N. J. King on the Rio Puerco near Albuquerque, N. Mex., shows that channel processes in ephemeral streams may not be uniform over long reaches. Resurvey in 1966 of a channel cross section established in 1939 by the U.S. Department of Agriculture, on the rivers near the town of Rio Puerco reveal no significant change in 27 years. However, in the upper reaches of Rio Puerco near Cuba, N. Mex., there is evidence of extensive aggradation since the arroyo cutting of the late 1880's. Monumented cross sections have been established along the Rio Puerco to accurately monitor the channel behavior in the future as part of the Vigil Network.[102]

A study by J. C. Mundorff (p. B77–B79) in southeastern Nebraska shows that manmade changes in Muddy Creek, near Syracuse, Nebr., about 50 years ago caused the formation of a channel scarp that has moved about 3½ miles upstream since 1914. Approximately 30,000 tons of sediment annually has been contributed to the Little Nemaha River as the result of this channel erosion.

[102] L. B. Leopold. 1962, The Vigil Network: Internat. Assoc. Sci. Hydrology Bull., v. 7, no. 2, p. 5–9.

Magnitude and frequency of geomorphic processes

A buried forest of redwood trees in growth position was exhumed by the floods of December 1964 which eroded terraces that stand 21 feet above stream level along Blue Creek, a tributary to the Klamath River in northern California. The maximum age of redwood and douglas fir presently growing on these terraces is 90 years on the basis of tree-ring counts. Allowing approximately 10 years for tree establishment, a minimum age of 100 years is assigned to these terrace deposits by E. J. Helley and V. C. LaMarche, Jr. The buried redwoods, which lived for an average of 550 years, died probably at, or shortly after, burial. A maximum age of the terraces on the basis of carbon-14 dating supplemented by ring counts is 925 ± 100 years. The evidence gathered suggests that the 1964 flood has a frequency of greater than 100 years but less than 925 years.

Cross sections of the Trinity River channel surveyed by J. R. Ritter show that the flood of December 25, 1964, caused pronounced changes in channel geometry. The thalweg eroded as much as 1.7 feet and aggraded as much as 4.8 feet, and the maximum measured lateral movement was 195 feet. Bed material became finer at aggraded sections and coarser at eroded sections. In general, the amount of channel alteration increased downstream.

River adjustment to altered hydrologic regimen

S. A. Schumm has found similarities in river behavior related to changes in sediment load and discharge between Great Plains rivers in the United States and the Murrumbidgee River in the Riverina area, Australia.

Multiple-regression analyses of both Australian and American river data demonstrate that channel width (w) and meander wavelength (l) are closely related to a parameter expressive of the type of sediment load moved through a stream channel (percentage of silt and clay exposed in the perimeter of each channel, M) and mean annual discharge (Q). The regression equations demonstrate that a change in channel dimensions can be influenced by a change in sediment load alone, and, in fact, they show that meander wavelength and channel width can both decrease with an increase in mean annual discharge, if the sand of the stream is significantly decreased (M increases), as follows:

$$l=1900\ \frac{Q^{0.35}}{M^{0.74}}$$

$$w=37\ \frac{Q^{0.40}}{M^{0.40}}$$

In both of these equations, 88 percent of the variation of the dependent variable is explained by mean annual discharge and channel silt-clay content ($r=0.94$).

The changes of channel morphology on the Riverina indicate that a modification of both discharge and type of sediment load can cause major changes in the morphology of a river system over many hundreds of miles of its length.

Topology of river networks

A study made by A. E. Scheidegger (r2001) of the statistical topology of river networks has shown that the confluences of rivers may be treated as inverted stochastic branching processes; thus a rational explanation is obtained for Horton's law of stream numbers. The drainage pattern into an intramontane trench was generated by the use of random numbers on a computer and compared with geographical observations. It was also possible to enumerate all the possible stream networks of a given order and to give expectation values for the number of stream segments of any order in a network of given order.

Characteristics of overland flow

Laboratory experiments by W. W. Emmett investigating the characteristics of the uniform flow of thin films similar to those found in overland flow have been designed to provide a basic understanding of flow on hillslopes. Results of experiments define a sharp break in the depth-discharge relation as the flow regime changes from turbulent to laminar at a Reynolds number of approximately 2,500. In the laminar region, the rate of decrease in depth with a decrease in discharge is less than for turbulent flow, and thus there is a concommitant rapid increase in the friction factor with decreasing discharge. The effect of adding additional roughness to the bed further increases the value of the friction factor. In the case of simulation of rainfall, the falling droplets further retard the flow in a manner analogous to adding roughness to the surface.

Field tests currently underway will relate laboratory results to hydraulic and geomorphic aspects of overland flow on natural hillslopes.

Erosional history from botanical evidence

Tree-ring dating and radiocarbon analysis were used by V. C. LaMarche, Jr., and R. F. Hadley to interpret the erosional history of Water Canyon, a small upland tributary of the Paria River in Boyle Canyon National Park, Utah. The botanical evidence gathered from local trees indicates that the erosional history of Water Canyon is similar to that of many other stream valleys in the Southwestern United States, with three distinct depositional episodes and three episodes of arroyo cutting since about 5700 B.C.

PLANT ECOLOGY

The close relationships between vegetation and such variables as soil moisture, macroclimates, microclimates, paleoclimates, water yields, and land use often permit the interpretation, and in some instances quantification, of past and present hydrologic events by various plant measurements. The interrelationships are usually complex, and much remains to be learned before man can attain an adequate understanding of his environment.

Runoff estimates from plant-community and soil-moisture measurements

Reasonable approximations of runoff and run-in moisture for each of 14 habitats in northeastern Montana have been obtained by F. A. Branson, R. F. Miller, and I. S. McQueen by computing the differences between annual precipitation and quantities of water evaporated and evapotranspired from soils occupied by different plant communities. Of the plant communities studied, 4 received run-in moisture and 10 had differing quantities of runoff. Almost twice the annual precipitation was evapotranspired by one plant community, a western wheatgrass (*Agropyron smithi*) meadow that received flood water from snowmelt in the spring. Runoff from one xeric habitat occupied by nuttall saltbush (*Atriplex nuttallii*) was more than 80 percent of the annual precipitation. Useful approximations of annual runoff from ungaged basins may be obtained by making measurements of soil moisture and precipitation and by determining the area occupied by plant communities.

Pollen analyses provide clues to past climates

From recent work in the upper Laguna Creek and Walker Creek tributaries of the Lower San Juan River in northeastern Arizona it appears possible to make pollen diagrams that are indicative of plant responses to climatic changes within the last 4,000 years. Samples for pollen analyses were collected by Deric O'Bryan, M. E. Cooley, and T. C. Winter in conjunction with terrace studies related to archeological sites. Field maps were made of terraces and other alluvial deposits, outlining the local distribution of three late Recent alluvial units. Profiles were charted at points where archaeological remains were found, some under

25 feet of sediments. Archaeological remains, dated by pottery-type identification and tree-ring study, tended to cluster in the 8th and 11th to 12th centuries A.D.

Gully formation associated with conversion from forests to cropland

In an attempt to determine the role of vegetation, including forests, pasture, and cultivated crops, upon streamflow, R. S. Sigafoos is studying the formation of gullies in the northern Virginia Piedmont. He believes that they are related to increased runoff rates associated with cultivation. If the cleared drainage basin is sufficiently large, channel downcutting will occur downvalley even along reaches through mature forest. The critical size of the cleared drainage basin and rates of runoff that result in downstream erosion have not been determined. Soil texture does not seem to be an important factor, as gullies occur in materials ranging from silty clay to sandy loams.

Tree growth and local hydrologic conditions

Results of tree-growth investigations in deciduous forests of southern Ohio indicate that variations in growth on different sides of a tree are little influenced by slope exposure or compass direction. These variations seem to be the result of varying degrees of growth suppression due to competition between adjacent trees. Preliminary results of investigations initiated in northern Virginia by R. L. Phipps suggest that the ability of trees to compete with each other varies between species and that trees least affected by the presence of surrounding trees are most likely to contain growth records which reflect local hydrologic and climatic conditions.

GLACIOLOGY

Glacier mass-balance studies

Detailed mass-balance measurements have been made on Gulkana and Wolverine Glaciers, Alaska; South Cascade Glacier, Wash.; and McClure Glacier, Calif., as the beginning phase of an International Hydrological Decade project which seeks to relate heat, ice, and water balances at representative glacier basins. L. R. Mayo reports that variations in accumulation and ablation over the surface of Gulkana Glacier (Alaska Range) were largely determined by persisting wind-scour and wind-drift effects. Maps of these wind-scour and wind-drift features ("scour pits" and "megadrifts"), combined with a relatively modest number of stake and pit measurements, were used for an accurate computation of the mass balance of this glacier. The net balance for the 1965–66 balance year was —23 cm of water equivalent. Annual accumulation and ablation rates were roughly twice as great on the maritime Wolverine Glacier (Kenai Peninsula), which is situated at only half the altitude of the more continental Gulkana Glacier. W. V. Tangborn's studies of South Cascade Glacier revealed a strongly negative net balance for the 1965–66 year (—108 cm) primarily due to low snow accumulation (14 percent less than 1957–66 average), the result of high freezing levels during many of the winter storms.

Glacier surges

An unusual number of glacier surges in southeastern Alaska and adjacent Yukon and British Columbia, Canada, was discovered in 1966 by Austin Post. Surges (also known as catastrophic advances or "galloping glaciers") are sudden increases in glacier flow from a normal 10 to 100 cm per day to about a meter per hour, which may result in ice advances of several kilometers in a period of 1 or 2 years. The huge Bering Glacier (200 km long and 5,600? sq km in area) was advancing along a 42-km wide front, and was exceptionally crevassed (indicating abnormally rapid movement) for at least 100 km upglacier from the terminus. Other surges, on large and small valley glaciers, were discovered in the Glacier Bay and Yakutat Bay areas and in the Icefield, Wrangell, and Skolai Mountains. These surges apparently are caused by some sudden change in the dynamic coupling of a glacier to its bedrock channel. The large number of surges observed in 1966 was apparently coincidental, and cannot be ascribed to a general change in climate.

Effects of earthquakes on glaciers

Studies by Austin Post of glaciers in and beyond the area affected by the 1964 Alaska earthquake dispute the commonly accepted Earthquake Advance Hypothesis. Snow and ice avalanching was found to be minor, and only a few apparent changes in glacier surface appearance, activity, or hydrologic regimen could be found. New surges and "normal" advances are more common in areas not affected by appreciable shaking. Some major rock slides and rockfall avalanches onto glaciers were caused by the earthquake, and these will have a long-term, continuing effect on the ablation rates of certain glaciers. Other rock slides occured before and after the earthquake, and there is no reason to believe that earthquakes are primarily responsible for the deposition of most superglacial drift.

Additional glacier studies

See pages A80–A81 for a description of the rate of movement of Teton Glacier, Wyo.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

U.S. Geological Survey silicate-rock standards

The U.S. Geological Survey has processed six new silicate-rock standards under the direction of F. J. Flanagan (r1399) to provide new reference samples to supplement G–1 and W–1. Complete conventional, rapid rock, and spectrochemical analyses by the Geological Survey are reported for a granite (replacement for G–1), a granodiorite, an andesite, a peridotite, a dunite, and a basalt. Analyses of variance for nickel, chromium, copper, and zirconium in each rock sample show that for these elements, the rocks can be considered homogeneous. Spectrochemical estimates are given for the nickel, chromium, copper, and zirconium contents of the samples. The petrography of 5 of the 6 rocks has been determined and their CIPW norms calculated.

Rapid rock analysis

A new rapid rock-analysis procedure has been described by Leonard Shapiro (p. B187–B191). Previously reported procedures for the rapid analysis of rocks have been supplemented by atomic-absorption spectrophotometric methods for CaO, MgO, Na_2O, K_2O, and MnO. A single solution prepared after fusion of the sample with lithium metaborate replaces the two solutions previously used. As a result of these modifications the time required for the complete analysis of a rock is halved.

Rapid determination of fluorine in minerals and rocks

A simple indirect determination of fluorine in minerals and rocks has been developed by Leonard Shapiro (p. D233–D235). Fluorine is volatilized from a 5-mg sample in a test tube as silicon tetrafluoride, using phosphoric acid to decompose the sample. The upper portion of the test tube is washed with dilute hydrochloric acid and the silica in the wash liquid is determined spectrophotometrically as molybdenum blue. With suitable standards, and samples containing less than 5 percent fluorine, accuracy is ± 2 percent relative or ± 0.02 percent absolute, whichever is larger.

Atomic-fluorescence spectrometry

The use of atomic-fluorescence flame spectrometry as an analytical tool is being investigated by J. I. Dinnin. Much of the work is being done with the aid of a demountable hollow-cathode lamp, developed by A. W. Helz, as a line source for the excitation of fluorescence in atomized metal vapors.[103 104] The fluorescence is measured at right angles with a monochromator equipped with chopper and phase-sensitive amplifier. Dinnin and Helz have found that the intensity of a demountable gold-cathode lamp is comparable to that of a commercially available gold high-intensity lamp. The atomized vapors of more than 30 elements have been tested for fluorescent activity. The fluorescent yield has been verified for 17 elements cited in the literature. The fluorescent activity of five additional elements—Pd, Ti, Zr, Cr, and Al—was found for the first time. Of these, the fluorescence of Pd, Ti, and Zr are thought to be sufficiently intense to be analytically useful. Thirteen elements yield detection limits in the parts-per-million range. The detection limits for five elements—Zn, Cd, Cu, Ag, and Au—are in the parts-per-billion range and should be amenable for development in analytical procedures to supplement other flame-spectrometric techniques.

Detection of mercury by atomic absorption

A commercially available atomic absorption spectrophotometer has been modified by W. W. Vaughn for use as a low-temperature mercury-vapor detector. The atomizer-burner assembly was removed and replaced by an aluminum chamber that is 2 inches square and 6 inches long and has end windows of optical quartz flats. The mechanically modulated light beam from a low-pressure ultraviolet lamp is synchronously passed through the monochromator adjusted to the 2,537–A line setting. The mercury vapor generated by a heated rock sample in a USGS thermo-amalgamator is carried through the chamber by an airstream flowing at a rate of 2,500 cu cm per minute. A sensitivity corresponding to a concentration of 5 ppb Hg is obtainable.

Atomic-absorption determination of bismuth in altered rocks

Small amounts of bismuth in altered rocks have been determined by F. N. Ward and H. M. Nakagawa (p. D239–D241) by atomic-absorption spectrophotometry after treating the sample with boiling nitric acid. The acid treatment solubilizes most of the bismuth in the materials investigated and the acid solution is atomized directly into the acetylene-air flame without prior enrichment or preconcentration. As little as 10 to 20 ppm Bi can be measured with a relative standard deviation of about 10 percent. The accuracy is com-

[103] J. I. Dinnin, 1967, Atomic fluorescence flame spectrometric detection of palladium, titanium, zirconium, chromium, and aluminum using a hot hollow cathode: Anal. Chemistry, v. 39, p. 1491–1493.

[104] J. I. Dinnin and A. W. Helz, 1967, Demountable hot hollow cathode lamp as excitation source in atomic fluorescence flame spectrometry: Anal. Chemistry, v. 39, p. 1489–1491.

parable to that of existing colorimetric and spectrographic methods. All these features, coupled with speed and simplicity, commend the proposed method for scanning large numbers of geologic samples in geochemical-exploration programs and related exercises.

Gold determination in rocks by atomic absorption

A routine method for determining the gold content of rocks has been developed by J. C. Antweiler and by Claude Huffman, Jr., J. D. Mensik, and L. B. Riley. The method consists of dissolving gold in the rock with an alkali cyanide solution, treating further with hydrobromic acid containing free bromine, extracting the dissolved gold with methyl isobutyl ketone, and estimating the gold by atomic-absorption spectrophotometry. This procedure was applied by Antweiler and J. D. Love (r0745) to the determination of gold in sedimentary rocks in northwest Wyoming. An average gold recovery of 90 percent was obtained from samples to which a measured amount of radioactive-gold tracer had been added. The true mean at the 90-percent confidence limit for a 20-ppb standard is between 22 and 17 ppb. Values at 10 ppb are almost as good, and those at 100 ppb are considerably better.

The atomic-absorption method was also combined by Huffman, and others with a fire-assay decomposition.[105] The rock sample is fused, with silver added as a collector for trace amounts of gold. The assay bead is then dissolved in acid. Gold is extracted into methyl isobutyl ketone and determined to a threshold value of about 10 to 20 ppb by atomic-absorption spectrophotometry. This procedure is now used extensively for reconnaissance studies for gold.

Radioactivation methods for gold in rocks

Two radioactivation-analysis methods have been developed for the determination of low concentrations of gold in rock samples. In a technique developed by H. T. Millard, F. W. Brown, and J. J. Rowe, a 100 to 500 mg sample is irradiated. After a short cooling period, the sample plus carrier is fused with sodium peroxide and then leached with water. A combination hydrolytic precipitation and reduction with hydrazine under alkaline conditions provide a rapid, early removal of the bulk of the radioactivity generated by the irradiation. Hydrochloric acid treatment of the precipitate leaves most of the gold in a residue which is dissolved in aqua regia. Extraction by ethyl acetate and subsequent precipitation by hydroquinone remove radiochemical impurities and the clean product is either gamma or beta counted. A correction must be made for protoactinium-233.

The second technique, studied by Millard and F. O. Simon, involves a fire-assay fusion of 15–30 g of sample. The lead button produced by this fusion is irradiated in a reactor for 1 to 4 hours, 2 mg of silver is added, and the button is cupelled. The silver bead is then gamma or beta counted without further radiochemical separation. These methods are applicable to determining gold concentrations in rocks containing as little as 0.1 ppb.

Fluorometric determination of gold

Gold(III) reacts with rhodamine-B in hydrochloric acid solutions to give a red-violet complex which has been used for the spectrophotometric determination of gold. Although the fluorescence of the complex has been reported, it has not been studied previously in detail nor has it been used for the determination of gold. The fluorescence of the rhodamine-B chloroauric acid complex has been studied by John Marinenko and Irving May. The fluorescence has a peak at 575 mμ, with optimum excitation at 550, and less sensitive excitation peaks at 410, 350, and 300 mμ. A fluorometric procedure has been developed for determining low levels of gold in rocks. The procedure consists of first roasting the sample to decompose sulfides and tellurides. Gold is then dissolved by the aeration-basic-cyanide method, leaving most of the sample insoluble. After removal of cyanide and oxidation of gold, the rhodamine-B complex is formed and extracted into isopropyl ether, and the fluorescence measured. For background-level determinations, an additional separation is made by precipitating gold with sulfur dioxide, using tellurium as a carrier. Levels of 5 to 2,500 ppb Au can be determined with good accuracy and precision on 10-g samples of rock.

Determination of palladium in the parts-per-billion range in rocks

F. S. Grimaldi and M. M. Schnepfe (p. C141–C144) have developed a procedure for determining acid-soluble palladium in rocks. The determination is made spectrophotometrically with p-nitrosodimethylaniline after separation of palladium by coprecipitation with a small amount of tellurium formed by reduction of tellurite with stannous chloride. The ignition temperature of the tellurium precipitate is critical, as the recovery of palladium above 400°C apparently is low. Higher ignition temperatures can be used, but the tellurium precipitation with palladium must then be made in the presence of microgram amounts of platinum. Palladium contents of 2.5 ppb in standard sam-

[105] Claude Huffman, Jr., J. D. Mensik, and L. B. Riley, in press, Determination of gold in geologic materials by solvent extraction and atomic absorption spectrometry: U.S. Geol. Survey Circ. 544. [Published Aug. 1967]

ple G–1 and 9.0 ppb in W–1 were found. Data for W–1 suggest that the palladium soluble in aqua regia may well represent the total palladium in rocks. Detailed data are given on the behavior of other noble metals.

Neutron-activation method for phosphorus in silicates

Phosphorus has been determined by L. P. Greenland (p. C137–C140) in eight USGS standard rock reference samples by neutron activation. After a 2-hour irradiation of 10-mg samples, phosphorus is separated in a radiochemically pure form by cation exchange, molybdate precipitation, magnesia precipitation, and copper sulfide scavenging. A final magnesia precipitation yields phosphorus in a form suitable for low-level beta counting. Subsequently, the percentage recovery for phosphorus is determined spectrophotometrically with the yellow molybdovanado-phosphoric acid. The results by this technique agree with conventional chemical analyses.

Comparison of potassium determinations by gamma-ray spectrometry and by chemical analysis

A combination of mathematical- and graphical-interpretation techniques applied by C. M. Bunker and C. A. Bush (p. B164–B169) to gamma-ray spectra obtained from whole-rock samples minimizes interfering effects of other radioisotopes and differences in sample size, weight, and density. With the present detection system, a minimum potassium concentration of about 0.10 percent is required to provide an adequate spectrum for quantitative interpretation. The coefficient of variation of 1-percent increments in a range of 0.10 to 3.4 percent K, ranges from 1.1 to 7.5 percent; the coefficient of variation for all samples is 2.68 percent.

OPTICAL SPECTROSCOPY

Volatile elements

A quantitative spectrographic method using a d-c arc in an argon atmosphere to determine trace amounts of Ag, Au, Bi, Cd, Ge, In, Pb, Sb, Tl, and Zn in geologic samples has been described by Charles Annell (p. C132–C136). A 20-mg sample mixed with 30 mg of anyhydrous Na_2CO_3 and 5 mg of powdered graphite is burned in a 25-amp d-c arc in an ambient argon atmosphere to give generally lower detection limits than is possible with normal air arcings. Detection limits, in ppm, are: Ag 0.20, Au 0.25, Cd 8, Sb 100, Zn 4, and the remaining elements 1. These improved detection limits were advantageous in studies of materials of astrogeologic interest—tektites, impactites, and meteorites. Volatile elements such as Ag, Pb, and Zn can provide clues to the thermal history of the materials.

A modification of this method by Sol Berman, J. L. Harris, and Charles Annell provides a new rapid semi-quantitative procedure for determining Zn and Pb in geologic materials. Detection limits of 4 ppm for Zn and 1 ppm for Pb are obtained. Various matrices are used to dilute NBS standard opal glass to prepare standards covering a wide range of rock types. For excitation, 20-mg samples mixed with 20 mg Na_2CO_3 and 5 mg graphite are burned 90 seconds (not to completion) with a 25-amp d-c arc in an argon atmosphere. The second-order spectral lines for Pb and Zn for unknown are compared in "semiquantitative" fashion with reference spectra of standards prepared with the identical procedure. This spectrographic method has advantages over wet geochemical-exploration methods and has been applied to geochemical-exploration programs.

Fluid inclusions

A primary fluid inclusion is usually a very small amount of fluid trapped in a cavity of a growing crystal. The cavity therefore contains a sample of the fluid from which the crystal formed. Analysis of such fluid aids in understanding the environment during formation of minerals and ores. The basic requirements of the analytical method are that (1) very small amounts of sample are used and (2) the method determines as many elements as possible that may be present. Joseph Haffty and D. M. Pinckney (p. B178–B180) have applied a spectrochemical procedure to this problem to determine calcium, magnesium, and sodium. Other elements readily may be added to this list. For a determination of the above elements, 200 μl of sample solution is evaporated on a pair of flat-top graphite electrodes. Uniarc excitation conditions are used to excite the residue. To minimize the effect of the wide ranges of element concentrations found in fluid inclusions, lithium is incorporated as a buffer and molybdenum as an internal standard. Calcium is determinable down to 0.2 ppm in the sample solution, magnesium down to 0.05 ppm, and sodium down to 0.8 ppm.

Spectrochemical matrices for noble-metal determination

Graphite, silica, Al_2O_3, KCL, Li_2CO_3, PbO, CuO Ag_2O, and GeO_2 were investigated by A. F. Dorrzapf and Sol Berman to find a matrix which would provide the best detection limits for the noble metals in spectrographic analysis. Germanium oxide proved to be the most favorable matrix. Silver oxide is less useful because of spectral background and precision problems.

Detection limits, in percent, to be expected from a 20-mg sample are:

GeO_2 matrix: Au 0.001, Pt <0.001, Os 0.0001, Pd 0.001, Rh 0.0001, Ru 0.0001, Ir <0.008.
AgO matrix: Au 0.00001, Pt 0.0001, Os 0.01, Pd 0.0001, Rh 0.0001, Ru 0.0001, Ir 0.008
Ru 0.0001, Ir 0.008.

For Au, Ag, Pt, Os, Pd, Rh, Ru, and Ir an improvement in detection limits was obtained when a 70 percent argon–30 percent oxygen a-c arc atmosphere was used instead of air.

Combined fire assay–spectrochemical method for platinum metals

L. B. Riley and Joseph Haffty have found a solution spectrochemical method that is very effective for determining the platinum-group metals in concentrates obtained by fire assay. Pt is determinable to 10 ppb of the original sample, Pd to 4 ppb, and Rh to 5 ppb. Silver or gold is used as a secondary collector and may be added to the samples if not present in sufficient amounts initially. Lead buttons are prepared from the gross samples by conventional fire assay. After cupellation and parting with nitric acid, the remaining beads are annealed and dissolved in aqua regia. The solutions are diluted to volume and analyzed spectrochemically.

Effective excitation for spectroscopic analysis is obtained with an intermittent d-c arc between two flat-end ¼-inch graphite electrodes on which 200 μl of sample solution has been evaporated.

A method for making artificial buttons was devised to study losses during the cupellation process. The "lead buttons" were prepared by evaporating known solutions of Ag, Au, Pd, and Pt in depressions made in 0.008-inch-thick lead foil. Synthetic samples for studies starting with crucible fusion were made by adding known solutions of the heavy metals to 15 g of sand for each fire-assay sample. All products and byproducts of crucible fusion, cupellation, and parting were examined, to track the elements being investigated.

Computer analysis of spectra

A. W. Helz is continuing investigation on the use of large high-speed computers for the complete analysis of photographically recorded spectra.[106] Instrumental development for this program started with the construction of a microphotometer which, with an intermediate-speed oscillograph, produced accurate representations of spectra, 1,250 A long, in about 3 minutes. This, in combination with a graphical digitizer and computer card punch, provided effective aids for testing parts of the computer program under development by F. G. Walthall.

Upon completion of programs for plate calibration, analytical line determination, and analysis reporting, spectra for lead and zinc in a large suite of samples previously analyzed for lead and zinc by conventional spectrographic methods were computer analyzed. Selected areas of the spectra of 160 samples were recorded with the oscillograph, lead and zinc lines were read with the digitizer, and the results were recorded on IBM cards. The computer-recorded results agreed very well with results obtained by conventional means. Although this tested sections of the computer program, the system is still impractical in its present form. An operator is required to recognize (isolate) spectral lines and index the digitizer. Only when the line finding is programmed will the full advantages of the computer be realized. In order to accomplish this degree of automation, extremely high precision and high speed microphotometry are required, owing to the high degree of complexity of the spectra. The designs of a microphotometer and recording system to meet these requirements have been completed. Readings will be taken every 5μ of spectral length, at a rate of 1,000 per second, digitized, formatted, and recorded on magnetic tape. The computer will be programmed to select the pertinent lines from this mass of data, relying for precision on "internal standard" spectral lines for fiducial points.

[106] A. W. Helz, 1965, The problem of automatic plate reading and computer interpretation for spectrochemical analysis, *in* Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525–B, p B160–B164.

X-RAY FLUORESCENCE

Slope-ratio technique for determination of trace elements

A new approach to solving matrix problems in X-ray fluorescence analysis has been developed by Frank Cuttitta and H. J. Rose, Jr. No prior knowledge of the chemical composition of the sample is required. Matrix effects are largely minimized by solution-dilution of the sample, whereas residual effects are evaluated by an addition technique. The ratio of the slope of the addition curve and that of the curve for the pure solution of the element is indicative of the extent of the matrix effect and furnishes the necessary data for applying corrections. The slope-ratio method has been used successfully to determine bromine in saline waters and zinc in silicates, and suggests general use for the determination of trace constituents in geologic samples. Application of the method to other instrumental techniques seems feasible.

Sodium and fluorine detection

By using a redesigned ultrathin polypropylene window on the gas-flow detector and a larger effective collimator path, H. J. Rose, Jr., and R. R. Larson have extended the application of the Survey's X-ray fluorescence facilities to include the detection of sodium and fluorine. Sodium determinations are made with a gypsum crystal analyzer and fluorine with a lead myristate crystal. Other crystals such as the potassium acid phthalate (KAP), hexadecyl hydrogen maleate (HHM), and octadecyl hydrogen maleate (OHM) with $2d$ spacings between 26 and 63 A are being investigated to improve detection.

Semimicroanalysis of rare-earth elements

H. J. Rose, Jr., and Frank Cuttitta have developed a combined chemical and X-ray fluorescence method for analyzing small amounts of rare-earth minerals of scarce natural occurrence. Seventeen elements consisting of the lanthanides, yttrium, and scandium can be determined on a 2-mg portion of the separated oxides of these elements. The oxides are dissolved in 1 ml of dilute acid, absorbed on cellulose powder, and pressed into a pellet for X-ray excitation. The method is independent of reliance on chemically analyzed samples, because solutions of the pure oxides are used as standards.

ELECTRON-PROBE ANALYSIS

Minor elements

Special conditions have been established by A. T. Anderson which permit the analysis, using the electron microprobe, of Ba to 0.005 percent in feldspars and of Mn to 0.01 percent in iron titanium oxides, pyroxenes, and sulfides.

The background at the wavelength of the element being determined is calculated according to the formula $\beta = A + cE$, where A is the background due to white radiation and cE is the background due to the matrix elements. A is related to the target element, E to the concentration of the interfering element, and c is a constant.

ANALYSIS OF WATER

Several advances in analysis techniques in water chemistry were perfected during the 1967 fiscal year. Also, a saving of time results from the use of a digital readout, an attachment to the atomic-absorption instrument which reads concentrations directly, for those elements which have previously been recorded manually.

Atomic-absorption methods for determining elements

Methods for determining Pb, Co, and Ni by atomic absorption have been set up. The elements are chelated with ammonium pyrrolidine dithiocarbamate and the metal chelates extracted with methyl isobutyl ketone. The elements may be concentrated approximately 80-fold, and it is possible to determine less than 1 mg per l. Data obtained by atomic absorption agree with data obtained by spectrographic methods.

A rapid and sensitive atomic-absorption method for the determination of chromium in fresh water has been developed by M. R. Midgett. Chromium is first oxidized to the hexavalent state with potassium permanganate, and the excess permanganate reduced with sodium azide. The pH is then adjusted to 2.4 and chromium chelated with ammonium pyrrolidine dithiocarbamate. The metal chelate is extracted with methyl isobutyl ketone, and the ketone layer containing the chromium chelate then aspirated. As little as 1 μg Cr per l can be detected. The results generally compared favorably with those obtained by other methods.

Determination of trace metals by emission spectroscopy

The separation and concentration of traces of heavy metals by the thioacetamide precipitation of their sulfides prior to determination by emission spectroscopy have been investigated by E. C. Mallory, Jr. Six elements, including As, Bi, Cd, Cu, Pb, and Sb, are precipitated completely from one sample aliquot made strongly acid ($0.2N$) with hydrochloric acid. Eight additional elements, including Al, Be, Cr, Fe, La, Ti, Zn, and Zr, are precipitated completely, or nearly so, from a second aliquot which has been adjusted with ammonia to a pH of 8.0. Palladium ion is added to each solution before precipitation as an internal standard, and stannous chloride and indium sulfate solutions are added to the acid and ammoniacal aliquots, respectively, as coprecipitants. The precipitated sulfides from each aliquot are filtered, ignited at 450°C, and each resulting residue then mixed with graphite powder for subsequent analysis by emission spectroscopy. The detection limit for all elements except As is 5 μg per l or less; the detection limit for As is about 10 μg per l.

X-ray fluorescence

Certain elements, such as Ca, K, Cl, S, and P, can be determined quantitatively by a simple X-ray fluorescence technique. In the method, developed by P. J. Dunton, 0.5 ml of water sample is evaporated on an aluminum planchet and the fluorescence intensity of each element to be determined is compared with that obtained from known standards treated identically. Background corrections are made by subtracting the intensity reading observed at a point near each element's fluorescence wavelength. About 1 ppm of each element can be detected with an overall accuracy of ±0.5 ppm.

Dissolved solids–specific conductance ratios

The ratios between the specific conductance and the total dissolved solids of certain ground waters of Mississippi have been calculated by Roy Newcome, Jr. Samples from Pliocene and Miocene aquifers of the coastal area have ratios which range from 0.70 for samples having a specific conductance of 150 μmhos, to 0.60 for samples of specific conductance of 600 μmhos. On the other hand the ratios for samples from Cretaceous aquifers of northeastern Mississippi range from 0.60 for samples of 150 μmhos specific conductance, to 0.575 for those of 600 μmhos. Establishment of such ratios permits a reasonably accurate estimate of the dissolved-solids concentration of a sample from the relatively simple measurement of its specific conductance.

Persistence of pesticides in water

In previous studies, D. F. Goerlitz and W. L. Lamar observed that Pesticide 2,4-D decomposes promptly in some samples while in others it is considerably more stable. Since the persistence of 2,4-D in water is significant in the analysis and study of this herbicide, recovery studies were applied to samples of water from areas that (1) have intense agricultural activity or a history of spraying with 2,4-D and (2) have less exposure to this herbicide. The results were quite significant. No substantial degradation of 2,4-D occurred in 20 days in samples from areas where its presence was apparently not sufficient to produce acclimated microorganisms. However, 2,4-D decomposed rapidly in samples from areas where spraying with 2,4-D was prevalent. When degradation was observed, 2,4-D decomposed to a concentration of about 200 ppt within 10 days. At this concentration, however, the rate of degradation was diminished. In 20 days, the concentration of 2,4-D was reduced to the 160- to 180-ppt level. The reduction to this level occurred both when 2,4-D was present in the sample when collected and when 2,4-D was added to samples from sources which had been sprayed or otherwise exposed to 2,4-D. The degradations of silvex and 2,4,5-T were also studied, but little or no loss of these herbicides was observed in 20 days.

HYDROLOGIC MEASUREMENTS AND INSTRUMENTATION

The U.S. Geological Survey now has 4,200 digital recorders in use, primarily in recording water-stage data. The results of a recent survey of representaitve districts indicate that ultimately digital recorders may be installed at 90 to 100 percent of the stream-gaging stations.

Digital recorders are also being used to record multiple hydrologic parameters which, together with recent advances in computer technology, provide greater flexibility in data-collection programs. These advances have prompted increased interest in automated data collection in related activities. Water-quality data are now being digitally recorded by the multiple-channel monitoring systems, and use of the digital recorder for collection of ground-water data is in the early experimental stage.

Discharge measurement by dye tracing

C. H. Scott and J. K. Culbertson have found that discharge-weighted samples taken at cross sections 4,000 and 6,500 feet downstream from a point of constant-rate injection of dye solution differ by only 2 percent. Discharge computed by this method checked the average of current-meter discharge measurements at 8 cross sections (262 cfs) within 0.4 and 1.5 percent, respectively. The dye was injected at 485 ml per sec. intentionally close to one tank; lateral mixing was computed to be only 68 and 81 percent complete at the 2 sites. The discharge-weighted samples were obtained by the ETR (equal-transit-rate) method of lowering a sampler at a uniform rate vertically at many equally spaced sampling points; the sampler opening was small enough to prevent it being filled completely before the entire cross section had been traversed.

F. A. Kilpatrick reports the successful use of the constant-injection method of introducing fluorescent dyes to measure water discharge under such widely varied conditions as in rough, cobblestoned mountain streams; constantly shifting sand-channel streams; irrigation canals, syphons, and flumes; and ice-covered rivers; and to measure unsteady flow, water gains and losses, and in-situ calibration of orifice meters.

Rapid measurement of discharge

A new technique for measuring the flow of large streams and tidal estuaries while rapidly traversing a stream by boat has been developed by G. F. Smoot, D. L. Cahal, and K. D. Medina. This technique utilizes the velocity-area method of determining discharge by dividing the cross section into incremental areas, determining a mean velocity for each increment, and summing the products of incremental areas and velocities to give total discharge. Instrumentation includes a recording depth sounder, a special current meter, and a vane with an indicator. These instruments are used aboard a small outboard-motor boat. Typical time required for measuring a stream 1,000 feet in width would be 2 to 3 minutes. (See also "Columbia River and Estuary" in section "Geology and Hydrology Applied to Engineering and Public Health, Transport of Radionuclides by Streams.")

Measurement of velocity of streamflow

Winchell Smith reports that field tests of six optical current meters, fabricated under contract from plans developed by the Geological Survey, have been conducted, and that velocities of 44 fps were measured in a concrete-lined channel near Los Angeles, Calif. Meters of this type are now available commercially. They provide instantaneous measure of surface velocity by direct observation from above the stream. The basic operating principle is similar to that of a stroboscope. Because no equipment is placed in the stream, there is no interference with the flow.

Measurement of turbulence

E. V. Richardson and R. S. McQuivey have determined that hot-film aneometers can be used to measure turbulence in ordinary water in the laboratory even though contaminants collecting on the film cause continuous shift in the voltage-velocity relation. Their procedure is to determine a base voltage-velocity relation for the probe in a filtered water supply. A pitot tube or some other transducer is used to measure the mean velocity at a point and the hot film to measure the voltage fluctuations corresponding to the velocity fluctuations at this point. The point velocity is used to determine the correct derivative of the voltage-velocity relation for conversion of the voltage fluctuations to velocity fluctuations.

In a companion study Richardson and McQuivey evaluated the hot film as a transducer by comparing turbulence measurements made in air using hot films with those using hot wires. They found little or no difference in turbulence-intensity measurements made using 0.002-inch-diameter hot films and those made using 0.002-inch-diameter hot wires, if the actual voltage-velocity relation was used to convert the RMS (root-mean-square) of the voltage fluctuations to the RMS of the velocity fluctuations. A similar comparison between 0.006-inch-diameter hot films and the 0.002-inch-diameter hot wires indicated that this diameter of films measured turbulence intensities about 10 percent lower than wires at Reynolds numbers less than 1.5×10^5 and 5 percent lower for Reynolds numbers greater than 1.5×10^5. It was also found that use of an empirical voltage-velocity relation of the form $E^2 = A\sqrt{U} + B$ (Kings law) gave turbulence intensity values that were too large when hot wires were used and too small when hot films were used.

Servomanometer response to water-level oscillations

Investigations by Winchell Smith, J. R. Beck, and C. R. Goodwin show that gas-purged servomanometer systems do not record the average water-surface elevation when there is wave action, but indicate a level below the mean elevation. The difference between the mean and indicated levels is a function of the magnitude and frequency of water-surface oscillations, the bubble rate, the internal volume of the gas-purged system, the response rate of the servomechanism, and the depth of water over the orifice. Under the worst conditions, where the orifice is near the water surface and oscillation rates are high, the water level indicated will be close to the low point of the surge. As the depth of water over the orifice is increased, effects of higher frequency oscillations are damped out and the indicated water level approaches the mean.

Detection of changes in bed materials

E. J. Helley, using a Zeiss Particle Analyzer to detect changes in the location of painted bed material during periods of high flow, has found that a mean velocity of 7.5 fps is capable of moving particles that have a median diameter as large as 0.85 ft and that the corresponding shear stress was 0.93 psf. The analyzer measures the size of particles by varying the diameter of a circle of light projected on a photograph of the particles and registering diameters of 48 size intervals on a telephone counter.

Automatic pumping-type sediment samplers

J. V. Skinner and George Carlson have designed and tested an automatic battery-powered pumping sampler that holds up to 121 quart containers or 144 pint containers. They also have designed a sample trap that permits collection of the sample before it passes through the pump. The sample trap, when used with a special stilling tank, can minimize pump wear caused by unusually coarse sediment.

A simplified pumping sampler has been designed by B. L. Jones and W. G. Shope. Its advantages include simplicity of construction, portability, and very low cost, approximately one-third that of previous samplers.

Freezing sampler for unconsolidated sediment

A freezing-type sampler consisting of a hollow aluminum plate 12 inches by 24 inches by 3/8 inch with a knife edge at its base, has been used successfully by V. C. Kennedy and E. D. McKee. When the sampler is driven into the sediment and a cold fluid circulated inside it, 1 to 1½ inches of sediment is frozen on each side of the plate in 20 minutes. After withdrawal, circulation of a warm fluid through the sampler permits removal of two opposing sections of frozen sediment which are stored in an insulated box with dry ice. Details of sedimentary structures in a wide range of materials can be seen.

The sampler is designed to be a useful tool in obtaining cross sections of subaqueous unconsolidated sediments in stream, estuarine, or shallow-marine environments. With suitable modification it may be of value in studies of deeper marine sediments.

Measurement of compressibility of fine-grained natural clays

R. G. Wolff reports the design and testing of a piezometer, using an electrical pressure transducer, which measures very small increments of pressure change in an environment of a wide range of total pressures. It can be used to determine the compressibility of fine-grained materials such as natural clays, and has the capability of sensitive pressure measurements to a depth of about 400 feet. In addition, it provides the option of calibration while in place in the field.

Analytical methods

Studies of methods for analysis of hydrologic and physical properties of rock and soil materials have resulted in a report by A. I. Johnson and others (r1704) and a paper by Johnson and R. T. Sniegocki (r2059) showing how laboratory analyses may be used to accurately predict the quantitative properties of aquifers and showing that results compare well with those obtained by field tests.

Improved technique for core sampling

In a study of the hydrologic effects of pesticide waste disposal, W. L. Lamar, D. F. Goerlitz, and L. M. Law have developed improved techniques for core sampling through a contaminated soil cover and procedures for the routine analysis of the core samples for pesticides and related waste products. The soil samples were extracted with an acetone-hexane mixture and processed for gas chromatographic analysis, using both electron capture and microcoulometric detection. A procedure was also developed for the measurement of total organic chlorine in the core samples. This provided a convenient way of determining the movement of the waste products in dump sites when a large number of complex chlorinated organic-waste products are present.

Measuring pH values at high pressures

An instrument capable of measuring pH values in submerged aqueous environments at high pressures with laboratory accuracy has been built and tested by J. L. Kunkler and others (p. B250–B253). It is the UNELAN (Underwater Electronic Analyser) and has been tested in the field to measure the pH of water in wells at pressures of up to 560 psi without damage. The accuracy of the pH measurements usually shows a difference of values of 166 to 169 mv in measurements with a 4.01 pH standard buffer and 6.86 pH standard buffer, a sensitivity which compares favorably with that of conventional electrodes.

Geophysical-logging techniques

A dozen different types of geophysical logs are being applied to the study of seven dissimilar ground-water environments throughout the United States and have provided geohydrologic information not otherwise obtainable, according to W. S. Keys. Results indicate that the neutron and gamma-gamma logs will provide new techniques for investigating permafrost and ice lenses.

Keys also reports (p. B242–B246) the development of an inexpensive magnetic-tape system for recording geophysical logs that will permit the rapid conversion of logs to a digital format. The system was developed and built by E. R. Bullard, Jr., and records raw pulses instead of digitizing an analog signal. The unmodified signal from a logging probe is recorded simultaneously with the conventional graphic log. During tape playback, all adjustments normally made during logging are possible. These include independent changes in horizontal scale, vertical scale, zero positioning, and time constant. The system permits a reduction in time spent at the well, office correction of operator errors and equipment malfunctions, and the plotting of logs at any time in a format consistent with the planned use, and provides for the economical storage and retrieval of data.

Evapotranspiration measurement

O. E. Leppanen describes the CRI (Cummings Radiation Integrator) as a large insulated evaporation pan which operates as a calorimeter. Its purpose is to measure the thermal-radiation exchange at a free water surface. It can eliminate the use of delicate and expensive instruments and the complicated processing of their data. The CRI uses pelleted polystyrene foam construction and a silicone-rubber-lined water container. Radiation data from the CRI agree with radiometer data to within 10 percent.

Digital telemetry system

G. F. Smoot reports the design of a digital telemetry system for transmitting data collected on the ADR (Analog-to-Digital Recorder). This system can be used to transmit single parameters or in conjunction with the multiple-channel water-quality monitoring system. The last reading from each parameter is stored in memory at the site and is updated each time a new value for that parameter is recorded. Transmission of data may be either by wire, radio, or microwave, or a combination of these. The system can be programmed to report automatically or may be interrogated manually.

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TOPOGRAPHIC SURVEYS AND MAPPING

MAPPING ACCOMPLISHMENTS

Objectives of the National Topographic Program

The major function of the Topographic Division of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Series covering the United States and other areas under the sovereignty of the United States of America. The individual series, at various scales, constitute a fundamental part of the basic data needed to inventory, develop, and manage the natural resources of the country. Other 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 and United States base maps. The Division is now publishing a special edition of quadrangle maps without contours or woodland symbols. This special printing is available for all new and reprinted maps.

Procedures for obtaining copies of the maps and map products of the Survey are given in the section "Publications Program, How to Order Publications."

Series and scales

All topographic surveys for standard quadrangle mapping, 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 Alaska maps, the publication scale is 1:63,360 or "inch-to-the-mile."

Quadrangle-map 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 75 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands, Guam, and American Samoa. 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 1,060 maps, published during fiscal-year 1967, covers unmapped areas equivalent to 2 percent of the area of the 50 States and of the islands referred to above. In addition, 402 new maps at a 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 7.

Map revision and maintenance

Map revision is necessary to show changes in man-made features, such as new roads, buildings, and reservoirs, and changes in the terrain. During fiscal-year 1967, 234 revised standard quadrangle maps of the 7½-minute series were published. Most of these newly revised maps were in urban areas or in the States that are 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 1967 and is now estimated to be about 7,200 maps (fig. 8).

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 1967, the Topographic Division amended the map-revision policy of April 1966 to include a special type of revision within the general category of limited revision. This new type of revision, known as interim revision, consists of adding all new cultural or planimetric features that are visible on aerial photographs and printing the added information on the published map in a separate color, magenta. It requires no fieldwork or contour changes, but relies primarily on photointerpretation. The interim-revision program was developed to enable the Survey to update maps more quickly and more often, and is being applied first to maps of urban areas. As pilot projects, four areas have been selected: Baltimore, Des Moines, El Paso, and Santa Maria (Calif.).

About 1,300 standard quadrangle maps were reprinted in fiscal-year 1967 to replenish stocks.

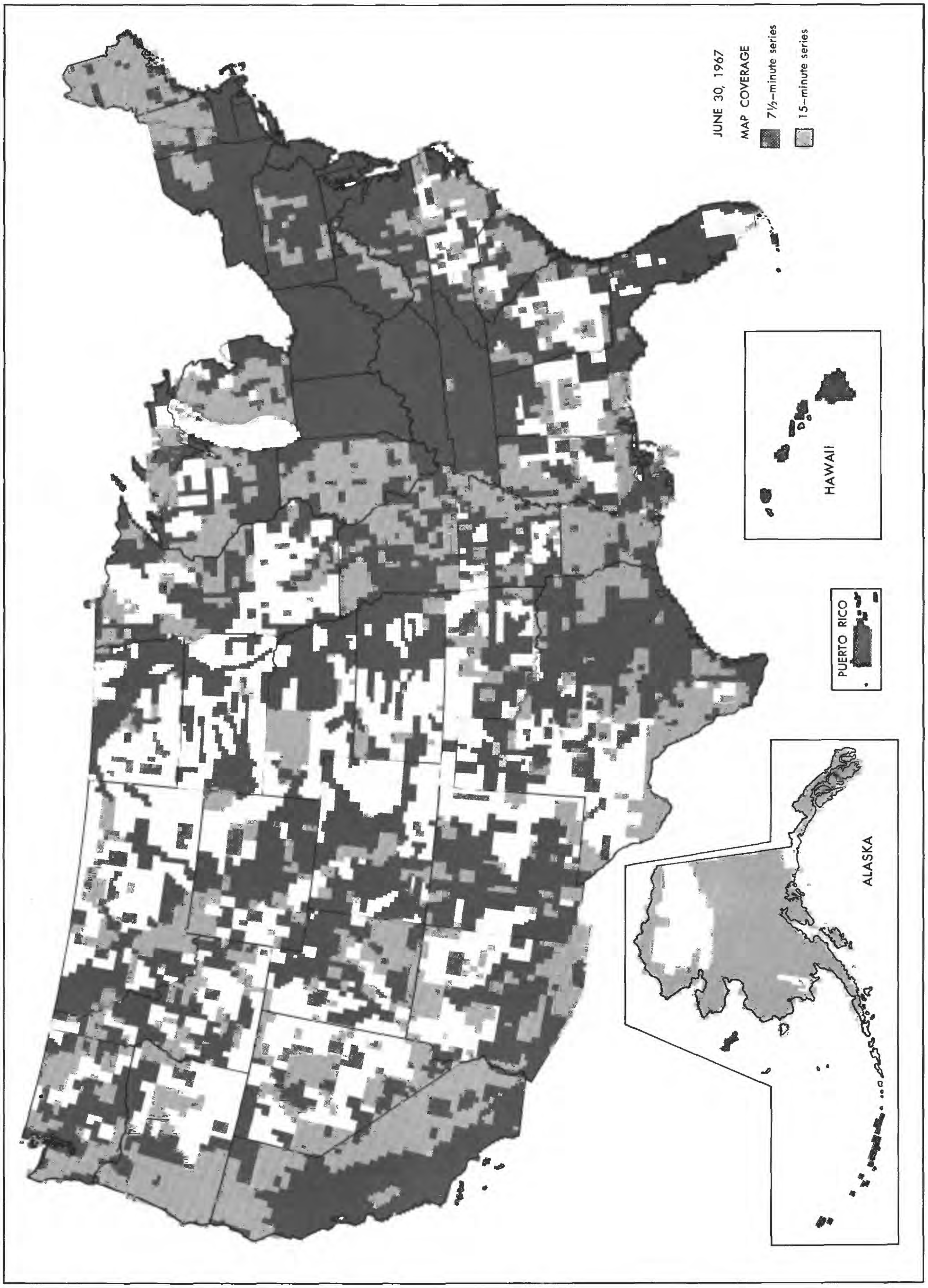

FIGURE 7.—Status of 7½- and 15-minute quadrangle mapping.

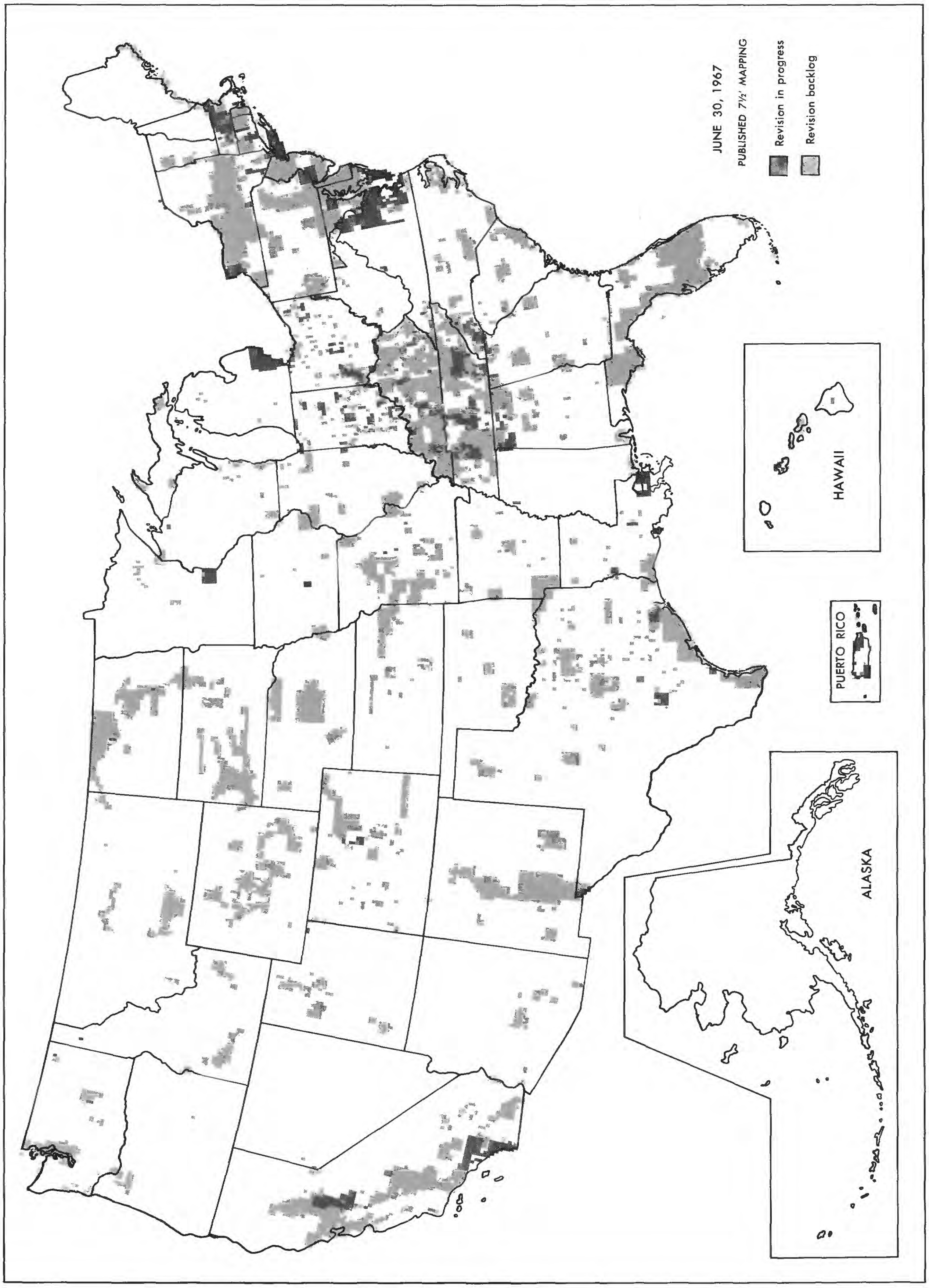

FIGURE 8.—Revision in progress and revision backlog of 7½-minute series topographic mapping.

1:250,000-scale series

The 48 conterminous States and Hawaii are completely covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service. These maps are being revised and maintained by the Topographic Division, with certain changes and additions to make them more suitable for civil use. The Geological Survey prepared and published a reconnaissance series for Alaska at a 1:250,000 scale in the past, and is now replacing these maps with an improved series based on larger scale source material and on photogrammetric compilations. Figure 9 shows revision work in progress on 1:250,000-scale maps.

State maps

State maps are published at 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 1:584,000 and 1:2,500,000. A State map of Hawaii is in progress.

The series of State maps, compiled according to modern standards, now contains 38 maps covering 42 States and the District of Columbia (fig. 10). 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, also shown in figure 10.

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 1967. Work in

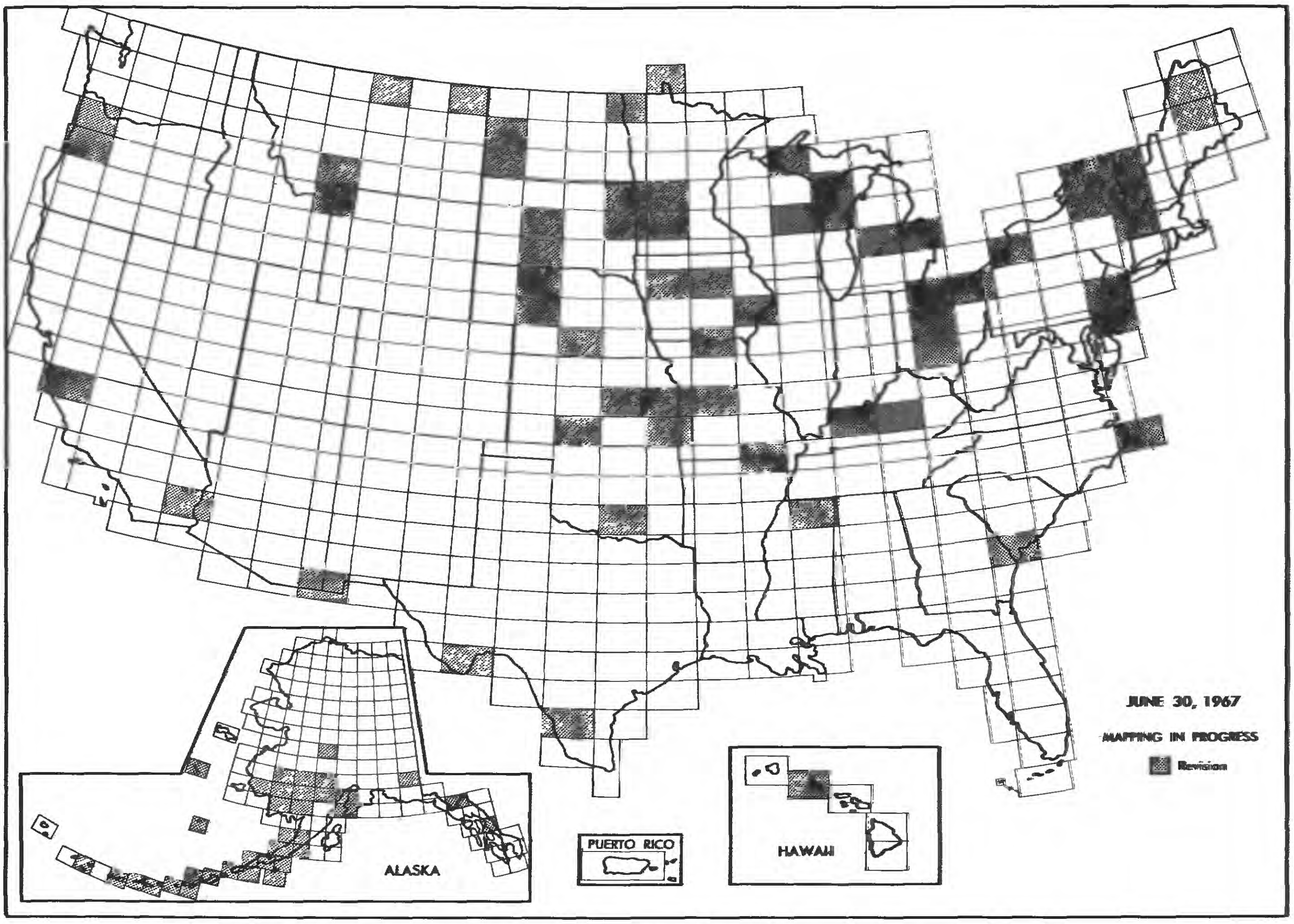

FIGURE 9.—Revision of 1:250,000-scale topographic mapping.

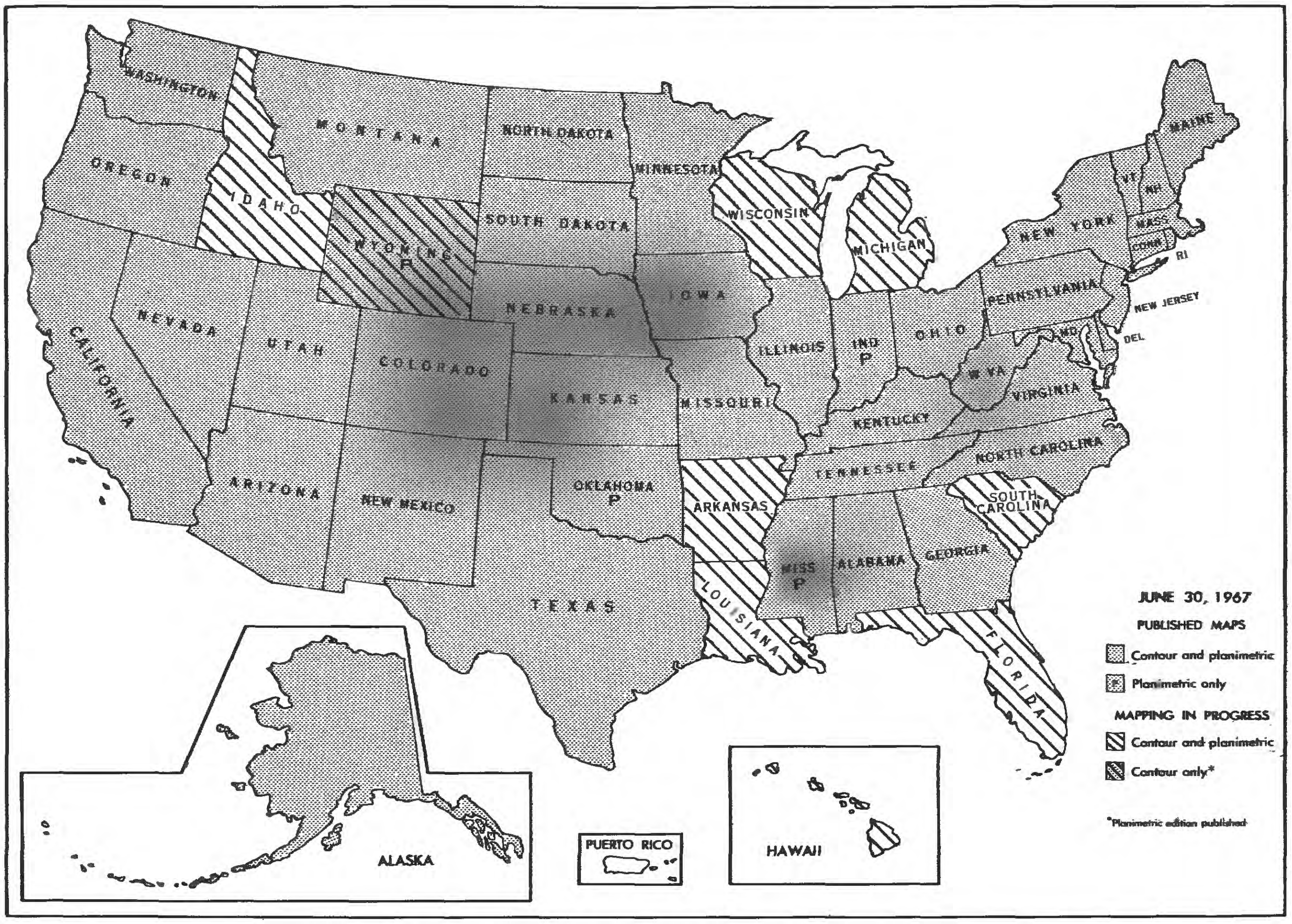

FIGURE 10.—Status of State topographic maps.

progress includes the revision of three 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.

PUBLISHED—Continued

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

Chicago, Ill.
San Juan, P.R.
Washington, D.C.

National-park maps

Maps of 41 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 the revision of three maps. Published maps in the national-park series include:

PUBLISHED

- Acadia National Park, Maine
- Badlands National Monument, S. Dak.
- Bandelier National Monument, N. Mex.
- Black Canyon of the Gunnison National Monument. Colo.
- Bryce Canyon National Park. Utah
- Canyon de Chelly National Monument, Ariz.
- Carlsbad Caverns National Park, N. Mex.
- Cedar Breaks National Monument, Utah
- Colonial National Monument (Yorktown Battlefield), Va.
- Colorado National Monument, Colo.
- Crater Lake National Park, Oreg.
- Craters of the Moon National Monument, Idaho
- Custer Battlefield, Mont.
- Devils Tower National Monument, Wyo.
- Dinosaur National Monument, Colo.–Utah
- Franklin D. Roosevelt National Historic Site, N.Y.
- Glacier National Park, Mont.
- Grand Canyon National Monument, Ariz.
- Grand Canyon National Park, Ariz. (2 sheets)
- Grand Teton National Park, Wyo.
- Great Sand Dunes National Monument, Colo.
- Great Smoky Mountains National Park, N.C.–Tenn. (2 sheets)
- Great Smoky Mountains National Park and Vicinity, N.C.–Tenn.
- Isle Royale National Park, Mich.
- Lassen Volcanic National Park, Calif.
- Mammoth Cave National Park, Ky.
- Mesa Verde National Park, Colo.
- Mount McKinley National Park, Alaska
- Mount Rainier National Park, Wash.
- Olympic National Park, Wash.
- Petrified Forest National 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 REVISION

- Grand Canyon National Park, Ariz.
- Petrified Forest National Park (formerly Monument), Ariz.
- Sequoia and Kings Canyon National Parks, Calif.

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 at a scale of 1:1,000,000. Eventually this military series will be modified slightly and published in the IMW series (fig. 11).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and 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 specification 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 1967, the Topographic Division contracted for aerial photography covering approximately 125,000 square miles in the United States. This total included 113,000 square miles of vertical photography, 1,000 square miles of convergent low-oblique photography, and 11,000 square miles of super-wide-angle photography. Contracts were also made for color photography covering 650 square miles.

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 1967. Four topographic engineers went to Antarctica during the austral summer of 1966–67 to obtain geodetic control for the topographic-mapping program to execute surveys in support of other disciplines. Also, a specialist in aerial photography was assigned to Christchurch, New Zealand, for photographic-liaison duty with the U.S. Navy.

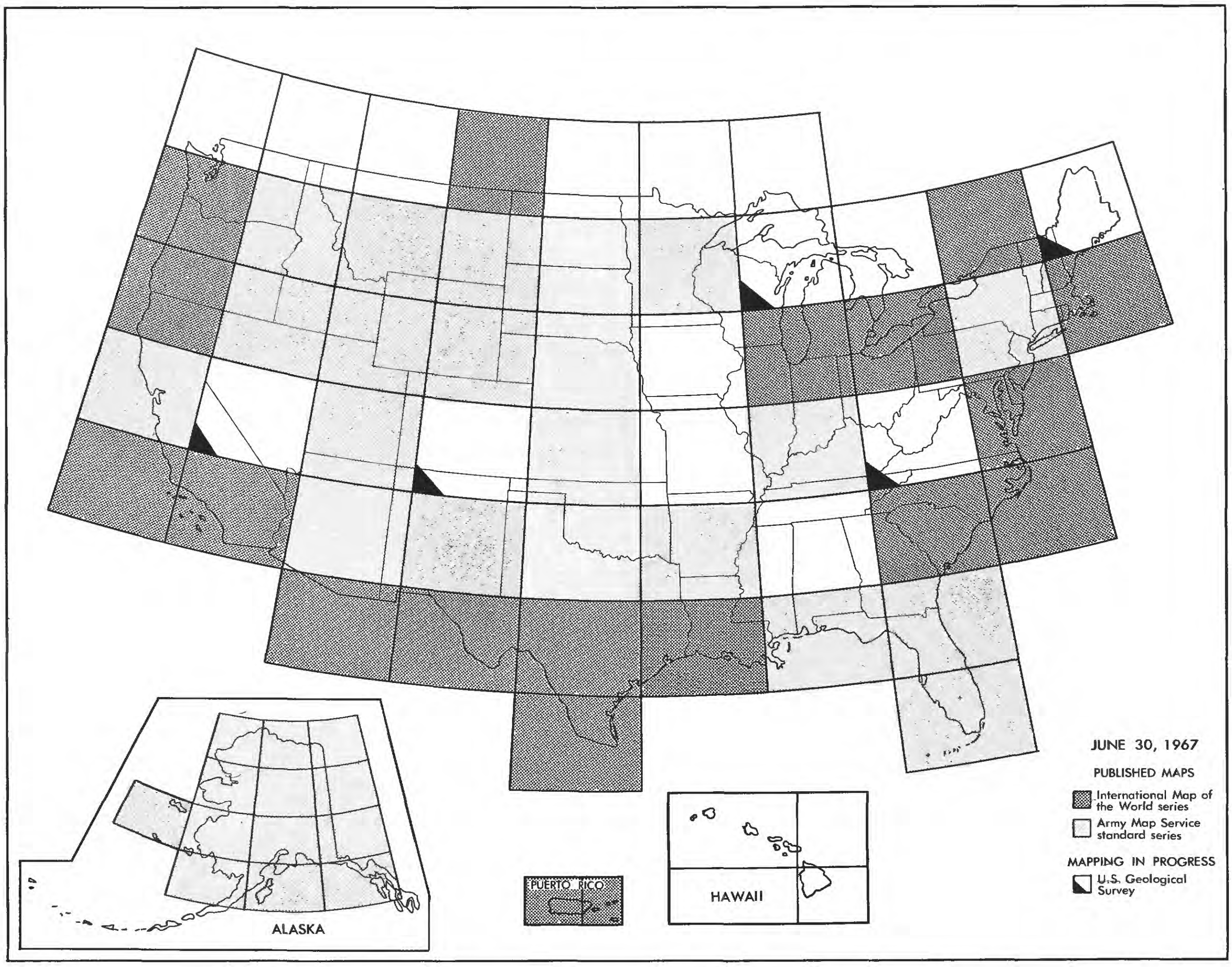

FIGURE 11.—Status of 1:1,000,000-scale topographic mapping.

Topographic field operations

J. F. Strange, C. E. Morrison, D. J. Faulkender, and T. K. Bray completed the first 925 miles of the electronic-distance traverse, part of the 3,400-mile multidiscipline Byrd Land Survey. The traverse began near Cape Colbeck on the Edward VII Peninsula and extended east through the Ford Ranges, across the Saunders Coast to Forrester Island on the Hobbs Coast, and will eventually be extended to the Jones Mountains. In addition, side shots totaling 300 miles were measured to obtain control in areas where there were few features suitable for angular intersection by theodolite. This season's work will furnish geodetic control for approximately 60,000 square miles of topographic mapping.

John Lozinyak, a Survey electronics specialist, traveled to Byrd Land in November to install an airborne repeater radio system in the helicopters used by the Survey field party.

Work performed for other disciplines included: (1) establishing a geodetic tie at McMurdo, between the CAMP AREA astronomic station and the geodetic satellite-tracking station, (2) remeasuring the ice movement stakes on the annual (seasonal) and fast ice between Hut Point and Koettlitz Glacier, (3) determining and astronomic azimuth for the beginning of the Byrd Station–Whitmore Mountains ice-strain net, and (4) establishing four new stations for the second-order triangulation net at McMurdo.

U.S. Navy Air Development Squadron 6 (VX–6) obtained aerial photographs for mapping in accordance with Geological Survey specifications. W. R. MacDonald was assigned to the U.S. Navy Photographic Laboratory at Christchurch, New Zealand, to advise on the quality of developed photographs and to assist with further planning and necessary reflights. MacDonald spent part of the season in Punta Arenas, Chile, where he served as visual navigator on all photographic missions originating there. Mapping-quality photography was obtained covering approximately 340,000 square miles.

This year weather forecasts over photomission areas were based on information gathered by weather satellites. With accurate weather data for the entire area of operations, the Squadron could plan daily operations with more assurance that there would be good weather when the plane arrived over the target area.

To insure greater accuracy in determining drift and flight-line position, and thus reduce the need for reflights and fill lines, a Doppler navigational system (model APN-153) was installed in the C-130 airplane. Although there were some minor difficulties, the system was considered successful and will be used in future operations.

Cartographic activities

The status of Geological Survey topographic mapping is shown in figure 12. Three 1:250,000-scale topographic maps were published in shaded-relief editions in fiscal-year 1967, completing the Queen Alexandra Range project. Two maps in the Heritage Range and four in the Queen Maud Mountains have been completed and are awaiting publication. Mapping at the same scale is in progress for 6 maps in the Queen Maud Mountains, 18 in North Victoria Land, and 6 in the Pensacola Mountains. Two 1:500,000-scale sketch maps in the Byrd Land area were published in shaded-relief editions, and three are in production; the maps are for sale to the public.

The two-piece plastic relief model of Antarctica, produced originally on an experimental basis and for limited distribution, is being revised. A 5,000-copy sales edition is planned.

NATIONAL ATLAS

Five maps of the National Atlas of the United States—Geology, Population Distribution, Monthly Sunshine, U.S. Land-Surface Form, and Alaska Land-Surface Form—have been published and are available for sale to the public. Two color tests were published during the year, and they showed that a wide variety of colors can be printed using only six colors of ink. As a result of these tests, many maps will be released which had been held pending final selection of printing inks.

RESEARCH AND DEVELOPMENT

In support of 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 maps and to reduce the cost of preparing them.

AUTOMATION IN PROGRAM MANAGEMENT

Research for automating a comprehensive topographic-program management system is beginning to yield results. Rapid central processing is coupled with a national telecommunications net to form the keystone of this system.

An electronic mapping and program data bank is being created. This library of historical, planning, budget, operational, and financial information about each quadrangle map is designed for automatic retrieval and analysis of data. Information is printed out either in typed lists or as a plot on a 1:4,500,000-scale sectional base map of the United States.

Parts of a new automated accounting management system are being installed. This system is integrated with the management data bank, automated operating programing, and Bureau personnel and payroll systems. Identifying and current reporting data are automated at their source, exploiting turnaround documents. Costs are accumulated in organizational cost centers and distributed according to direct hours of labor. Automated reports cover costs, schedules, production, and man-hours.

Another main segment of the management system is the resources-balancing system. Up to 30 discrete operations for each of 6 years are scheduled and balanced with resources by the computer solving the mathematical program model by linear programing. Management can override the system. Alternative solutions are readily developed. Computer reports include forecasts of costs, production, manpower, and schedules.

FIELD SURVEYS

Determining atmospheric refraction from meteorological data

Past atmospheric-refraction studies have produced results that were either inconclusive or of limited application. The fact remains that, for lack of a sufficiently refined index of refraction, errors due to atmospheric refraction are present in measurements obtained over optical sightlines or microwave measur-

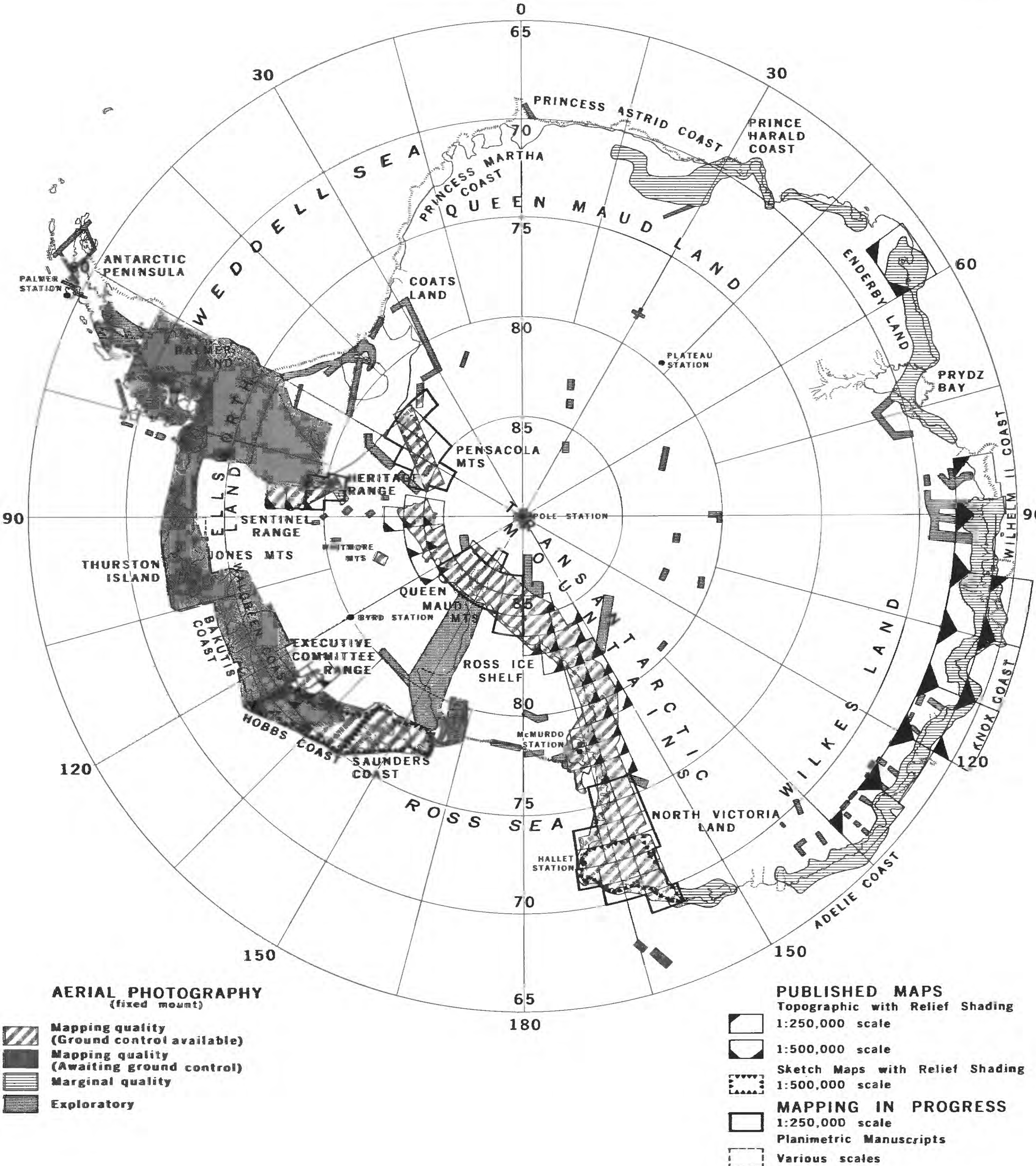

FIGURE 12.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1967.

ing-beam paths; it follows, therefore, that the accuracy of vertical-angle surveys can be significantly improved if a practical field method can be found to determine the effective index of refraction for each observational course.

Limited field tests conducted during the past 2 years in the vicinity of Washington, D.C., indicate that there is a direct, simple relationship between atmospheric refraction and net solar radiation. Field observations to obtain further data for atmospheric refraction studies began in June 1967. Vertical-angle observations are being taken on eight sightlines over various types of terrain in Virginia, Colorado, and California. The lengths of the sightlines range from 6 to 20 miles, and the elevation differences vary from 400 feet to 4,000 feet. The observation stations have geodetic elevations ranging from 200 feet to nearly 10,000 feet.

Precise vertical-angle observations with first-order theodolites are being made over each course at 1-hour intervals from sunrise to sunset for a period of about 5 days. Concurrently, measurements of barometric pressure, temperature, humidity, and net solar radiation are being recorded at each station.

Analysis of the data provided by these measurements is expected to show (1) what effect terrain profiles and various atmospheric conditions have on refraction, (2) whether there is a significant systematic elevation in valley-to-peak sightlines, and (3) whether net solar radiation is, indeed, directly related to refraction.

Horizontal-control surveys

In the winter field season of 1966–67 the Geological Survey began establishing basic horizontal control to second-order standards. This action makes effective an agreement between the Geological Survey and the Coast and Geodetic Survey whereby the Geological Survey will establish any new basic horizontal control needed for the National Topographic Mapping Program according to procedures that will make the control a part of the National Geodetic Network. As part of the agreement, new specifications for second-order horizontal-control surveys were prepared jointly by the two agencies. The specifications are unique in that they provide detailed requirements for establishing second-order horizontal control by traverse with electromagnetic distance-measuring equipment.

To provide an adequate means of testing, evaluating, and adjusting optical instruments used in control surveys, a field-instrument calibration system has been installed in the research laboratories at McLean, Va. The system contains a central pedestal, which holds the instrument to be tested, and 3 pedestals, which hold a total of 5 collimators, on the circumference of a 5-foot-radius circle whose center is at the instrument stand. Three of the collimators are in a horizontal plane, at the same height as the instrument to be tested, and are separated by 45° of arc. The other two collimators are in a vertical plane, 20° of arc above and below the central collimator.

This array of collimators permits effective sight distances ranging from 5 feet to infinity to be simulated in the laboratory, and field observations to be duplicated without the variable and uncertain effects of unstable setups and atmospheric changes. Although the system is used primarily for tests of theodolites, it is also adaptable to levels and alidades.

The calibrator system has proved to be both efficient and reliable, permitting rapid corrective adjustment of malfunctioning instruments; convenient evaluation of newly acquired instruments; standard acceptance tests for new and reconditioned instruments; and analysis of standard surveying procedures for efficient matching with instrument precision.

Tests are being conducted in the laboratory and under actual field conditions to evaluate theodolites equipped with five-wire reticles. The five-wire angle measurements are taken along with corresponding single-wire measurements to provide direct comparisons of the time needed for each method and the precision of the results obtained. These comparisons will be used to specify the number of angle measurements needed to attain required orders of accuracy.

Geodetic applications for laser devices so far have been limited to distance measurement. The most promising development is a laser light source for the Model 4 Geodimeter. The laser approximately doubles the night range of the Geodimeter and more than quadruples the daylight range.

For second-order horizontal-control surveys, truck-mounted towers are needed in some areas to obtain the required 1-mile minimum distance between traverse stations. However, previous tests indicated that the towers needed further stabilization for high-order surveys. Proposed stabilizing techniques of shading the tower, insulating the instrument tube, and double-bracing the inner tower were tested during the Tuscaloosa, Ala., field project. Results from these tests indicate that, with partly cloudy to cloudy skies and very light winds, angles of second-order accuracy can be measured from truck-mounted towers extended up to 66 feet in height.

Tests are being continued on a recently developed tripod brace. This brace, which can be adapted to most tripods, provides greater stability in setups and protection against collapse of tripods when setups are made on smooth surfaces.

Remote control of field instruments

A radio-controlled device for on-and-off switching of remote signal lights, unattended electronic distance-measuring (EDM) instruments, and radio altimeters is under development. The device is used with conventional two-way radios. At the radio transmitter station, a discrete audiofrequency tone is broadcast. This tone is received at the remote station and, through an induction-coil pickup over the radio speaker, is fed to an amplifier and then through a narrow-band filter which activates the command control. The radio command control is inactive and uses little power except for the instant of receiving the tone. Normal voice transmission will not activate the control; therefore, the radios can also be used for normal communications. Local tests of the prototype model have shown 100-percent response from a distance of 43 miles. To date, the device has been tested with only one receiver command station. Experimentation is continuing to develop the capability of accommodating a minimum of five discrete command stations.

A base-station altimeter equipped with a radio transceiver is being developed to provide elevation reference data or air-pressure data on demand by a geologist or surveyor engaged in fieldwork. The instrument consists of a Wallace & Tiernan surveying altimeter with a constant-speed motor-driven optical scanning arm which senses the location of index marks and the pointer on the elevation scale of the altimeter. The optical sensing head contains a focused light source and a photodiode. The light and diode are positioned on the scanning arm so that the light strikes the mirrored ring on the face of the altimeter and reflects back to the diode. As the scanner traverses the dial and passes over an index mark or the pointer, there is a momentary reduction in the level of light which strikes the photodiode, causing a sharp change in its electrical resistance. The diode is the controlling element of an audiofrequency oscillator whose output is fed to the radio transmitter for broadcast. Therefore, when the scanner passes over the pointer or an index mark, a tone burst is generated.

The radio altimeter does not transmit continuously. When the operator at a remote station needs a reading from the base station, he transmits the signal tone which turns on the scanning mechanism and switches the base transceiver from "receive" to "transmit." Then he times the intervals between index tone bursts and the pointer tone burst with a stopwatch. From the rate of scanning and the timed interval between index and pointer tone bursts, he computes the reading of the pointer by simple arithmetic.

For example, assume that the portion of the altimeter scale from 0 to 3,700 feet is scanned in 60 seconds and the interval between the 0 and pointer tone bursts is timed at 31.8 seconds. The elevation reading is then computed as $31.8/60 \times 3{,}700 = 1{,}961$. Because the graduations of the altimeter scale are not uniform, the computed elevation reading must be corrected by an amount scaled from a calibration chart.

Normally an altimeter is given a light tap before a reading is taken, to make sure that the pointer is swinging free. In designing the radio altimeter, it proved to be unnecessary to include a mechanical agitator because the sound waves from the switch-on signal provide the desired effect. After a data transmission, a delayed-action relay turns off the scanner and switches the radio back to "receive."

PHOTOGRAMMETRY

Analytical aerotriangulation

At Bowling Green, Va., the direct geodetic constraint method of analytical aerotriangulation, programed for the Burroughs 220 computer, is being used to establish photogrammetric control for eleven 7½-minute quadrangles and provide data on time, cost, and accuracy for evaluation of the method in production. Tests carried out to determine the most suitable method of preparing diapositives, which are measured on a monocomparator to provide computer input in the form of x and y photocoordinates, have indicated that diapositives prepared in a projection printer with the corrector plate removed and diapositives printed by emulsion-to-emulsion contact produced the best and about equal results. Other tests are planned to verify these results.

The diapositives are being measured in an environmentally controlled room, where temperature and humidity changes that affect the positional accuracy of the photographic images have been eliminated. The temperature is controlled within $\pm 2°$F, and humidity is maintained at 55 ± 5 percent. Air filtration is 95-percent effective on 0.3-micron particles. Similar rooms are planned for other offices to provide environments suitable for measurements of micron accuracy.

A magnetic-tape copy of the computer program for the multiple-station analytical triangulation (MUSAT) system, written for the IBM 7090/7094 computer, has been obtained from the U.S. Army Engineer Topographic Laboratories. This program is a further development of the direct geodetic constraint method of analytical aerotriangulation and is capable of solving blocks of as many as 100 photographs. It incorporates a number of important provisions, including the capability of treating the photograph coordinates and the ground-control coordinates as externally observed values. This program is being converted for use with the IBM System/360 computer.

Semianalytical aerotriangulation

In semianalytical aerotriangulation, the stereomodel rather than the photograph is the basis for the data supplied to the computer program. Conventional analog stereoplotting instruments, equipped with encoders and analog-to-digital (A/D) conversion and readout equipment, provide x and y (and sometimes z) coordinates in digital form from the stereomodel. These stereomodel coordinates are correlated, adjusted, and fitted to ground control by automatic data processing.

All regional offices of the Topographic Division have been equipped with A/D conversion and readout equipment. Each of these systems contains a master control unit capable of supporting four remote-control subunits, each of which is attached to a specially adapted stereoplotter. The semianalytical methods of aerotriangulation have now replaced the stereotemplet method, which has been standard for more than a decade.

The relative merits of semianalytical and fully analytical aerotriangulation cannot be evaluated until several comparators are available to test the fully analytical methods. Meanwhile, the semianalytical methods offer a practical solution to production problems.

Image correlator

An instrument for image correlation is being obtained for research. This instrument may potentially be applied to many Topographic Division operations, including automation of stereoplotters, hovering control for the ABC system, and automation of instruments in field surveys. The instrument consists of a scanner, electronic control circuitry, and a microscope assembly which will at first be attached to a comparator. The scanner matches images within 1 micron and accommodates scale differences within a range of $\times \pm 2$.

StereoImage Alternator system

The StereoImage Alternator (SIA) that has recently been developed by J. W. Knauf (p. D284–D288) is a system that eliminates the need for anaglyphic filtering and permits direct viewing of stereoscopic models in projection-type stereoplotting instruments. The SIA system incorporates three synchronized rotating shutters, two in the projection field and one in the viewing field (with segments for both eyes), to flash alternate images from the left and right projectors so that each eye sees only the image from the corresponding projector. The three shutters are powered by miniature stepping motors controlled by pulse and logic circuitry which synchronizes the motors. The motors are run fast enough to eliminate perceptible flicker.

Elimination of the anaglyphic filters increases the stereomodel resolution and the amount of light reaching the eyes of the stereoplotter operator. Moreover, color photographs can now be used in projection-type stereoplotting instruments. Preliminary tests of the SIA system are complete, and production units are being installed.

Vision-care program

One of the critical tasks in preparing topographic maps by photogrammetric methods is the observation and precise measurement of stereomodels formed in stereoscopic plotting instruments. This task makes exacting demands on the visual acuity and depth perception of the instrument operators, demands that are distinctly different from ordinary seeing and reading.

Extensive research in the visual and environmental elements of stereoscopic observation and map plotting have demonstrated that the visual efficiency of operators of plotting instruments can be brought to and maintained at a high level by a vision-care program that includes frequent optometric examinations and the use of eyeglasses specially adapted to the individual operator and the physical conditions in which he views the stereomodel formed by a particular instrument. The special glasses permit the operator to view and work with stereomodels for long periods of time without eye fatigue and strain due to constant accommodation and convergence at the required short viewing distances (8–10 inches).

A vision-care program has been started, covering 240 operators of stereoplotting instruments in the Denver, Colo., and Arlington, Va., offices. The program will later be extended to cover all operators. Benefits expected from the program include greater productivity, a shorter training period for new operators, and indefinite extention of the high-efficiency service of each employee.

Automatic coordinate-plotting system

The Autoplot (Roy Mullen, D289–D291), and off-line automatic coordinate-plotting system, has been developed for preparing the base sheets needed for topographic-map compilation. The system is particularly compatible with analytical methods of aerotriangulation, which will provide ready-to-run magnetic tapes containing all the data to be plotted, scribed, and labeled on individual base sheets.

The hardware of the Autoplot consists of (1) a rack-and-pinion coordinatograph modified with stepping motors to provide the x and y motions, and a triple-function plotting head to plot individual points, scribe lines, and write labels and other alphameric information; (2) a magnetic-tape reader; and (3) an electronic logic and control unit, which interprets the signals received from the tape reader and controls the functions of the plotter. Plotting resolution of the system is 0.0005 inch, and plotting error over the 48- by 48-inch table does not exceed 0.0015 inch.

A prototype unit of the Autoplot has been built and tested. Components are now on order for building four additional units, to be installed in the map-production offices of the Survey.

Camera acceptance tests

For about 15 years, all aerial cameras to be used for taking the aerial photographs needed for Geological Survey map compilation have been tested on the surveys multicollimator camera calibrator. Diapositives made from the test-film exposures have been set up in a stereoplotting instrument,, and the acceptability of the camera has been evaluated on the basis of stereomodel measurements. This stereoscopic method of testing is only approximate, but it is directly related to the way the aerial photographs are used in map compilation.

To eliminate the effects of variability and uncertainty in visual depth perception, an analytical method of evaluating the test exposures has been developed, in which the diapositives are measured on a comparator and the resulting photocoordinates are processed on an electronic computer. No unusual discrepancies have been obtained with the new method, which seems to indicate that the older method is generally valid even though it is more subjective.

Long-focal-length camera

A Zeiss precision aerial camera with a 12-inch focal length has been obtained for research to determine whether photographs taken with such a camera provide significant advantages, in definition and resolution, over conventional mapping photographs taken with a 6-inch camera. Potential applications include preparation of photomaps, mapping of heavily timbered areas, and interim revision, in which photointerpretation is highly critical because the revised maps are published without a field check.

CARTOGRAPHY

Automatic color separation

Preparation of color-separation drawings for multicolor map printing is a time-consuming, costly operation that could be greatly simplified by automation. In the present standard method, each of the half-dozen or more drawings for a quadrangle map is prepared manually by scribing on coated plastic sheets.

An automatic line-following instrument, developed in the machine-tool industry to control metal-working machines, is being adapted to a coordinatograph for research in automatic scribing. The instrument consists of an optical scanning mechanism, an electronic control console, servomotors to move the coordinatograph scribing head in the x and y directions, and a solenoid to raise and lower the scribing point.

When the optical scanner is placed on a line on a guide drawing, it senses the relative amount of light reflected from each side of the line. Control circuits in the console, which govern the motion of both the scanning head and the scribing head simultaneously, cause the scanner to follow the line by keeping the amount of light reflected from the two sides of the line equal. Any tendency of the scanner to veer off the line is instantly corrected. While the scanner follows the guide line, the scribing point duplicates it on a coated plastic sheet fixed to the plotting table of the coordinatograph.

Improved map design

After several years of research in possible improvements in the cartographic appearance of standard topographic maps, an experimental edition of the Wausau West, Wis., 7½-minute map was printed in September 1966. This experimental map contains all the proposed changes in map design and format which could be accepted on the basis of cartographic feasibility and operational convenience and economy.

Changes in the format of data in the margin of maps include a new bolder type-face for the quadrangle name, which is positioned in diagonally opposite corners for convenient reference in filing. Bolder type is used for the credit legend, and the grouping of credit notes has been rearranged. More information is included in the bar scale. Important cities in the State are identified in the quadrangle-location diagram. And labels for the Universal Transverse Mercator grid are printed in blue to correspond with the blue grid ticks.

Interior changes in map design include new, differentiating type styles for most feature names and labels. A bolder, more distinctive type is used for place names. Shaded type is used for township names. Names of hydrographic features are printed in blue. The green and pink tints denoting woodland and urban areas have been reduced 50 percent for a more pleasing appearance.

Although the changes in typography have been approved, the new typefaces will not be available for the Survey typesetting equipment for at least a year. Other changes will be adopted during fiscal year 1968.

Photomapping

Several technical improvements in preparing photomaps were developed in the past year. Of these, the most important are (1) the highly successful use of scale-stable paper prints for making the master mosaics, which makes it possible to eliminate join lines between adjacent photographs and (2) the replacement of photoline and phototone negatives by image-tone and accent-tone negatives and a surface-tone positive. In making the pressplates for photolithographic printing, these new film copies of the master mosaic have specific uses.

The surface-tone positive is used for printing the ground color only where the ground is visible—that is, around but not over detail images, such as trees and houses. The image-tone negative is used for printing the detail images. This separation of ground and image colors avoids the undesirable effects of surprinting different colors. The accent-tone negative provides clear, accurately positioned edge enhancement of detail images.

Further improvements in photomaps are expected to result from current research in characteristics required of photographs to be used for making photomaps; ways of providing more uniform tonal quality (density), exposure to exposure and map to map; better masking for names and elevations; and a more practical way of holding register in printing.

Production of the photomaps of the Okefenokee Swamp is proceeding satisfactorily, with 5 of the 16 maps published as of June 1967 and the other 11 to be published before the end of calendar year 1967.

Fieldwork has been completed on the trial quadrangle of the Florida Everglades, and a trial printing of the photomosaic in color has been run. The trial printing indicates that some color adjustments will be needed for the final printing.

Other photomapping projects now in progress include a four-photograph Watercote color mosaic showing the land, water, and lake bottom along a portion of the Great Salt Lake shoreline; an experimental photomap of Accomac, Va., covering coastal sands, dunes, and vegetation; and experimental photomaps at scales of 1:12,000 (urban areas) and 1:24,000 (other areas) covering representative terrain in other parts of the country.

COMPUTER TECHNOLOGY

A new Computer Center Division has been established in the Geological Survey. It will provide computing services and related technical support to the scientific and administrative activities of the Geological Survey and to other bureaus and offices of the U.S. Department of the Interior. Computer facilities include an IBM System 360 Model 65 computer as the central facility in Washington, D.C. This is connected via voice-grade telecommunication lines with IBM System 360 Model 20/30 computers at Menlo Park, Calif.; Denver, Colo.; Flagstaff, Ariz.; and Rolla, Mo. The field terminals are extensions of the central facility and provide essentially the same computational capability at the field locations as is available at the Washington, D.C., headquarters. The result is an interdependent nationwide computing system which provides scientists and engineers with a powerful tool for numerical analysis, data handling, and information storage and retrieval. The system is expandable in increments and should satisfy existing increasing workload requirements.

The Geological Survey's new nationwide computing system expedites work in volcanology and earthquake studies, earth-orbiting satellite surveys, lunar-geology studies, national topographic-mapping program, minerals investigations, hydrologic studies, and in the preparation of the National Atlas. Computer-technology applications related to the above disciplines and investigations are reported elsewhere in this chapter and are generally listed under the heading "Computer Technology." in the index.

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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, and maps are printed and sold by the Survey.

All books, maps (exclusive of topographic quadrangle maps), and related publications published by the Geological Survey are listed in "Publications of the Geological Survey, 1879–1961," and in yearly supplements that keep the catalog up to date. New publications are announced each month in "New Publications of the Geological Survey." All these lists of publications are free upon request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Books, maps, charts, folios, and atlases that are out of print can no longer be purchased from any official source. They may be consulted at many libraries, and some can be purchased from dealers in secondhand books.

PUBLICATIONS ISSUED

During fiscal year 1967, 252 technical book reports were published (281 in fiscal year 1966). Maps printed totaled 4,004, comprising some 16,248,000 copies (19,868,000 in fiscal year 1966) as follows:

Kind of map	FY 1966	FY 1967
Topographic	3, 593	3, 330
Geologic and hydrologic	314	231
Maps for inclusion in book reports	208	228
Miscellaneous, and maps for other agencies	403	215
Total	4, 518	4, 004

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 660 authorized commercial dealers throughout the United States who sell Survey maps locally.

In addition to approximately 66,696,941 maps and books on hand at the beginning of the year, 13,597,466 copies of new and reprinted maps and 1,464,900 copies of books (including popular-information leaflets) were received into the Survey's distribution system. A total of 7,452,750 copies of maps were distributed, including 387,700 index maps.

Also during the fiscal year the Geological Survey distributed without charge, for official use, 1,712,600 books (including information booklets), nearly 2 million maps (including nearly 400,000 index maps), 177,000 copies of the monthly announcement of new publications, and 400,000 map-symbol sheets.

More than 5½ million maps were sold and $1,431,993.79 was deposited to miscellaneous receipts in the U.S. Treasury ($1,093,823.76 in fiscal year 1966).

The total distribution was implemented by 474,850 individual orders. The following table shows a comparison between Geological Survey map and book distribution through Survey offices during fiscal years 1966 and 1967. A part of the relatively large increase shown for the Washington Distribution Section is attributable to the accelerated publication and resulting distribution of popular-information leaflets.

Distribution point	FY 1966	FY 1967	Change (percent)
Washington	4, 554, 850	5, 563, 892	+18
Denver	2, 768, 850	2, 920, 089	+5
Alaska	75, 100	73, 976	−1
12 other Survey offices	566, 700	607, 393	+6
Total	7, 965, 500	9, 165, 350	+13

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 Offices listed on page A223.

Circulars 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 DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, 1200 SOUTH EADS ST., ARLINGTON, VA. 22202, and for areas west of the Mississippi River to the DISTRIBUTION SECTION, U.S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLO. 80225. Remittances should be check or money order payable to the Geological Survey, or 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 Offices listed on page A223. Residents of Alaska may order Alaska maps from the DISTRIBUTION SECTION, U.S. 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 "New Publications of the Geological Survey." Each State index shows the areas mapped, with listings of special and United States maps, and gives lists of Geological Survey offices from which maps may be purchased and also of local agents who sell maps.

Advance material available from current topographic mapping is indicated on quarterly releases. This material, including such items as aerial photography, geodetic-control data, and preliminary maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is given on the quarterly issues. Requests for indexes or inquiries concerning availability of advance materials should be directed to the MAP INFORMATION OFFICE, U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

State surface-water and quality-of-water records

Pending 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 that are entitled "Water Resources Data for [State]" and consist of two parts: 1 "Part 1, Surface Water Records," and "Part 2, Water Quality Records" on the basis of State boundaries. Distribution of these basic-data reports, which are free on request, is limited and primarily for local needs. Those interested should write to the State or States for which records are needed.

State water-resources investigations folders

A series of 8- by 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, the Virgin Islands, Guam, American Samoa, and Okinawa. As the programs change, the folders are revised. The folders are available free on request to the U.S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Open-file reports

Open-file reports include unpublished manuscript reports, maps, and other material made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation by the public are given in press releases or other forms of public announcement. In general, open-file reports are placed in one or more of the three Geological Survey libraries: ROOM 1033, GENERAL SERVICES BLDG., WASHINGTON, D.C.; BLDG. 25, FEDERAL CENTER, DENVER, COLO.; and 345 MIDDLEFIELD ROAD, MENLO PARK, CALIF. Other depositories may include one or more of the Geological Survey offices listed on pages A223 to A227, or interested State agencies. Many open-file reports are replaced later by formally printed publications.

COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1967

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
- 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

Department of the Army:
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Corps of Engineers

Department of Defense:
- Arms Control and Disarmament Agency
- Advanced Research Projects Agency
- Defense Intelligence Agency
- Office of Scientific Research

Department of Health, Education, and Welfare:
- Public Health Service

Department of Housing and Urban Development
Department of the Interior:
- Bonneville Power Administration
- Bureau of Commercial Fisheries
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- Federal Water Pollution Control Administration
- National Park Service
- Office of Saline Water
- Office of Territories:
  - American Samoa
  - Guam
  - Virgin Islands
- The Alaska Railroad

Department of Justice
Department of the Navy:
- Office of Naval Research
- Petroleum and Oil Shale Reserve

Department of State
Department of Transportation:
- Office of High Speed Ground Transportation

District of Columbia
Environmental Science Services Administration:
- Weather Bureau

Executive Office of the President, Office of Emergency Planning
Federal Aviation Agency
General Services Administration
National Aeronautics and Space Administration
National Science Foundation
Puerto Rico:
- Department of Industrial Research, Economic Development Administration
- Department of Public Works
- Economic Development Administration
- Water Resources Authority

Tennessee Valley Authority
Veterans Administration

STATE, COUNTY, AND MUNICIPAL COOPERATORS

[Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency]

Alabama:
- Alabama Department of Conservation
- Alabama Highway Department
- City of Mobile
- City of Montgomery, Water Works and Sanitary Sewer Board
- Geological Survey of Alabama

Alaska:
- Alaska Department of Fish and Game
- Alaska Department of Health and Welfare
- Alaska Department of Highways
- City of Anchorage
- City of Haines
- Greater Anchorage Area Borough
- Greater Juneau Borough

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Interstate Stream Commission
- Arizona State Land Department
- Buckeye Irrigation Company
- City of Flagstaff
- City of Safford
- City of Scottsdale
- City of Tucson
- City of Williams
- Flood Control District of Maricopa County
- Gila Valley Irrigation District

Arizona—Continued
- Maricopa County Municipal Water Conservation District No. 1
- Metropolitan Water District of Southern California
- Navajo Tribal Council
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Co.
- Superior Court, County of Apache

Arkansas:
- Agricultural Experiment Station, University of Arkansas
- Arkansas Geological and Conservation Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley–East Kern Water Agency
- Bolinas Harbor District
- Calaveras County Water District
- City of San Diego
- City of Santa Barbara
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- Department of Conservation, Division of Mines and Geology
- Department of Fish and Game
- Department of Water Resources
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Imperial Irrigation District
- Lake County Flood Control and Water Conservation District
- Los Angeles County
- Los Angeles County Department of County Engineers
- Los Angeles County Flood Control District
- Los Angeles County Waterworks District
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Newhall County Water District
- Orange County Flood Control District
- Orange County Water District
- Reclamation Board
- Riverside County Flood Control and Conservation District
- San Benito County
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Bernadino Valley Water Conservation District
- San Francisco City and County, Public Utilities Commission
- San Francisco Water Department
- San Gorgonio Pass Water Agency
- San Luis Obispo County Flood Control and Water Conservation District
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Maria Valley Water Conservation District

California—Continued
- Soquel Creek County Water District
- State Water Quality Control Board
- 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 Engineer
- Colorado State Mining Industrial Development Board
- Colorado Water Conservation Board
- Costilla Creek Compact Commission
- Inter-County Regional Planning Commission, Denver
- Rio Grande Compact Commission
- Southeastern Colorado Water Conservancy District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- Connecticut State Highway Department
- Connecticut Water Resources Commission
- Greater Hartford Flood Commission

Delaware:
- Delaware Geological Survey, University of Delaware
- Delaware State Highway Department

District of Columbia:
- Department of Sanitary Engineering

Florida:
- Broward County
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Fort Lauderdale
- Cities of Miami and Miami Beach
- City of Naples
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Collier County
- Dade County
- Florida Board of Parks and Historic Memorials
- Florida Geological Survey
- Florida State Road Department
- Hillsborough County
- Jacksonville City Commission
- Jacksonville City Engineer
- Orange County
- Polk County
- Trustees of the Internal Improvement Fund

Georgia:
- Department of Mines, Mining, and Geology, State Division of Conservation
- State Highway Department
- Water Quality Control Board

Hawaii:
- Board of Land and Natural Resources
- City and County of Honolulu
- Department of Land and Natural Resources
- Honolulu Board of Water Supply

Idaho:
- Idaho Department of Highways
- Idaho Department of Reclamation

Illinois:
- Forest Preserve District of Cook County
- Fountain Head Drainage District
- Northeastern Illinois Metropolitan Area Planning Commission
- Sanitary District of Bloom Township
- State Department of Public Works and Buildings:
  - Division of Highways
  - Division of Waterways
- State Department of Registration and Education:
  - Geological Survey Division
  - Water Survey Division
- The Board of Trustees of the University of Illinois, Civil Engineering Department
- The Metropolitan Sanitary District of Greater Chicago

Indiana:
- Indiana Department of Natural Resources
- Indiana Division of Water, Department of Natural Resources
- Indiana State Board of Health
- Indiana State Highway Commission

Iowa:
- City of Cedar Rapids
- City of Fort Dodge
- City of Iowa City
- Iowa Agricultural Experiment Station, Iowa State University of Science and Technology
- Iowa Geological Survey
- Iowa Institute of Hydraulic Research
- Iowa State Conservation Commission
- Iowa State Highway Commission
- Iowa State University

Kansas:
- City of Wichita
- Kansas State Board of Agriculture
- Kansas State Department of Health
- Kansas State Geological Survey
- Kansas State Water Resources Board
- State Highway Commission of Kansas

Kentucky:
- City-County Planning Commission of Lexington and Fayette County
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky Research Foundation

Louisiana:
- Louisiana Department of Conservation
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Compact Administration

Maine:
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- Bureau of Water Supply of Baltimore
- Maryland Department of Health
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Maryland State Roads Commission
- Washington Suburban Sanitary Commission

Massachusetts:
- Department of Public Works
- Division of Highways, Department of Public Works

Massachusetts—Continued
- Division of Waterways, Department of Public Works
- Metropolitan District Commission
- Water Resources Commission

Michigan:
- Michigan Department of Conservation:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Minnesota Department of Administration
- Minnesota Department of Conservation, Division of Waters
- Minnesota Department of Highways
- Minnesota Geological Survey
- Minnesota Iron Range Resources and Rehabilitation Commission

Mississippi:
- City of Jackson
- Harrison County Board of Supervisors and Harrison County Development Commission
- Jackson County Port Authority and Jackson County Board of Supervisors
- Mississippi Board of Water Commissioners
- Mississippi Geological, Economic, and Topographical Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pearl River Valley Water Supply District
- Tombigbee River Valley Water Management District

Missouri:
- Conservation Commission, Fisheries Division
- Curators of the University of Missouri, Physical Plant Department
- Department of Public Health and Welfare of Missouri, Water Pollution Board
- Missouri Division of Geological Survey and Water Resources
- Missouri State Highway Commission

Montana:
- Endowment and Research Foundation at Montana State University
- Montana Bureau of Mines and Geology
- Montana State Fish and Game Commission
- Montana State Highway Commission
- Montana State Water Resources Board

Nebraska:
- Game, Forestation, and Parks Commission
- Metropolitan Utilities District
- Nebraska Department of Water Resources
- State Department of Health
- State Department of Roads
- University of Nebraska, Conservation and Survey Division

Nevada:
- Nevada Bureau of Mines
- Nevada Department of Conservation and Natural Resources
- Nevada Department of Highways

New Hampshire:
- Department of Resources and Economic Development, Geologic Branch, Department of Geology
- New Hampshire Water Resources Board

New Jersey:
- Camden County Planning Board
- County of Bergen
- Delaware River Basin Commission

New Jersey—Continued
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Conservation and Economic Development:
  - Division of Fish and Game
  - Division of Water Policy and Supply
- New Jersey Department of Health, Division of Environmental Health
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University

New Mexico:
- City of Gallup
- Costilla Creek Compact Commission
- New Mexico Department of Public Health
- New Mexico Institute of Mining and Technology
- New Mexico Interstate Stream Commission
- New Mexico State Engineer and New Mexico School of Mines
- New Mexico State Engineer
- New Mexico State Highway Commission
- Pecos River Commission
- Rio Grande Compact Commission

New York:
- Board of Hudson River, Black River Regulating District
- Brighton Sewer Commission, District No. 2
- City of Albany, Department of Water and Water Supply
- City of Auburn
- 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:
  - Board of Supervisors
  - Water Authority
- County of Westchester
- Department of Conservation:
  - Division of Lands and Forests
  - Division of Water Resources
- New York City Department of Water Supply, Gas, and Electricity and New York City Board of Water Supply
- New York State Department of Commerce
- New York State Department of Public Works
- New York State Office of Atomic and Space Development
- Oswegatchie River–Cranberry Reservoir Commission
- State Department of Health
- Town of Bethlehem
- Village of Nyack, Water Department

North Carolina:
- City of Asheville
- City of Belhaven
- City of Burlington
- City of Charlotte
- City of Durham
- City of Greensboro
- City of Lenoir
- City of Morganton
- City of Winston-Salem
- Division of Mineral Resources, North Carolina Department of Conservation and Development
- New Hanover County Board of Commissioners
- North Carolina Department of Water Resources

North Carolina—Continued
- North Carolina State Highway Commission
- North Carolina State University
- Pitt County Board of Commissioners
- Town of Waynesville
- Wake County Board of Commissioners

North Dakota:
- North Dakota Geological Survey
- North Dakota State Highway Department
- North Dakota State Water Conservation Commission
- Oliver County

Ohio:
- City of Columbus, Department of Public Works
- Miami Conservancy District
- Ohio Department of Health
- Ohio Department of Highways
- Ohio Department of Natural Resources:
  - Division of Geological Survey
  - Division of Water
- Ohio River Valley Water Sanitation Commission

Oklahoma:
- City of Oklahoma City
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Soil Conservation Board
- Oklahoma Water Resources Board
- State Department of Health

Oregon:
- Burnt River Irrigation District
- Clatsop County
- City of Astoria
- City of McMinnville
- City of Monmouth
- City of Portland
- City of The Dalles
- City of Toledo
- Coos Bay North Bend Water Board
- Coos County, Board of Commissioners
- Douglas County, Board of Commissioners
- Eugene Water and Electric Board
- Lane County, Board of Commissioners
- Mosier Irrigation District
- Office of the State Engineer
- Oregon Board of Higher Education
- Oregon State Game Commission
- Oregon State Highway Commission
- Oregon State University, Department of Fisheries and Wildlife
- Oregon State Water Resources Board
- Washington County, Board of Commissioners
- Water Resources Department, Office of the State Engineer

Pennsylvania:
- Chester County Commissioners
- Chester County, Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia
- Delaware River Master
- Lehigh County Soil and Water Conservation District
- Pennsylvania Department of Agriculture, Soil and Water Conservation Commission
- Pennsylvania Department of Forests and Waters
- Pennsylvania Department of Health

Pennsylvania—Continued
- Pennsylvania Department of Highways
- Pennsylvania Department of Internal Affairs, Bureau of Topographic and Geologic Survey
- Pennsylvania State University

Rhode Island:
- State Department of Public Works:
  - Division of Harbors and Rivers
  - Division of Roads and Bridges
- State Water Resources Coordinating Board

South Carolina:
- City of Spartanburg
- Commissioners of Public Works, Spartanburg Water Works
- Pickens County Planning and Development Commission
- South Carolina Pollution Control Authority
- South Carolina Public Service Authority
- South Carolina State Development Board
- South Carolina State Highway Department
- Spartanburg County Planning and Development Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- East-Dakota Conservancy Subdistrict
- South Dakota Department of Highways
- South Dakota State Geological Survey
- South Dakota State Water Resources Commission

Tennessee:
- City of Chattanooga
- City of Lawrenceburg
- City of Memphis, Board of Light, Gas, and Water Commissioners
- City of Murfreesboro
- City of Oak Ridge
- Metropolitan Government of Nashville and Davidson County
- Tennessee Department of Conservation and Commerce:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Highways
- Tennessee Department of Public Health
- Tennessee Game and Fish Commission

Texas:
- City of Austin, Department of Planning
- City of Dallas
- City of Houston, Public Works
- Pecos River Commission
- Orange County Commissioners Court
- Rio Grande Compact Commission
- Sabine River Authority of Texas
- 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 Engineer
- Utah State Road Commission
- Utah Water and Power Board
- Utah Water Research Lab

Vermont:
- Office of the State Geologist, Vermont State Development Department

Vermont—Continued
- Vermont Department of Highways
- Vermont Water Resources Board

Virginia:
- City of Alexandria
- City of Newport News
- City of Norfolk:
  - Department of Public Works
  - Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Division of Mineral Resources, Virginia Department of Conservation and Economic Development
- Virginia Department of Conservation and Economic Development
- Virginia Department of Highways

Washington:
- City of Port Angeles
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Department of Natural Resources
- Municipality of Metropolitan Seattle
- University of Washington
- Washington Division of Mines and Geology
- Washington State Department of Conservation
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Washington State Department of Natural Resources
- Washington State Pollution Control Commission
- Western Washington State College

West Virginia:
- Clarksburg Water Board
- Division of Water Resources, West Virginia Department of Natural Resources
- Morgantown Water Commission
- West Virginia Department of Natural Resources
- West Virginia Geological and Economic Survey
- West Virginia State Road Commission

Wisconsin:
- Public Service Commission
- Regents of the University of Wisconsin, Geological and Natural History Survey
- Southeastern Wisconsin Regional Planning Commission
- Wisconsin Conservation Department
- Wisconsin Department of Resource Development
- Wisconsin State Highway Commission

Wyoming:
- City of Cheyenne
- City of Rawlins
- Wyoming Geological Survey
- Wyoming Natural Resource Board
- Wyoming State Agriculture Commission
- Wyoming State Engineer
- Wyoming State Highway Commission

OTHER COOPERATORS AND CONTRIBUTORS

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 N.W., Washington, D.C. 20242; 202 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; 303 233-3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 325-6761

PUBLIC INQUIRIES OFFICES

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 (213 688-2850)	7638 Federal Bldg., 300 N. Los Angeles St.
San Francisco, 94111	Jean V. Molleskog (415 556-5627)	504 Custom House, 555 Battery St.
Colorado, Denver, 80202	Lorene C. Young (303 297-4169)	15426 Federal Bldg., 1961 Stout St.
Texas, Dallas, 75202	Mary E. Reid (214 749-3230)	602 Thomas Bldg., 1314 Wood St.
Utah, Salt Lake City, 84111	Maurine Clifford (801 524-5652)	8102 Federal Bldg., 125 South State St.
Washington, Spokane, 99201	Eva M. Raymond (838-4611 ext. 111, 112)	U.S. Court Bldg., West 920 Riverside Ave.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of September 1, 1967. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

CONSERVATION DIVISION

Location	*Official in charge* and telephone number*	*Address*
Alaska, Anchorage, 99501	Leo H. Saarela (m) (907 277-0578), Alexander A. Wanek (c) (907 277-0570), W. J. Linton (o) (907 277-0579).	P.O. Box 259; 207 Skyline Bldg., 218 E St.
California, Los Angeles, 90012	Merritt B. Smith (c) (213 688-2846), D. W. Solanas (o) (213 688-2846).	7744 Federal Bldg., 300 N. Los Angeles St.
Sacramento, 95814	Kenneth W. Sax (w) (916 499-2203)	8030 Federal Bldg., 650 Capitol Ave.
Bakersfield, 93301	Harry Lee Wolf (o) and E. E. Richardson (c) (805 327-7201).	309 Federal Bldg., 800 Truxtun Ave.
Colorado, Denver, 80202	Edward R. Haymaker (o) (303 297-3211), John P. Storrs (m) (303 297-4038).	15428 and 15444 Federal Bldg., 1961 Stout St.
Denver, 80225	George H. Horn (c) (303 233-8168)	Building 25, Federal Center.
Denver, 80202	William C. Senkpiel (w) (303 297-3316)	15407 Federal Bldg., 1961 Stout St.
Durango, 81302	Jerry W. Long (o) (303 247-5144)	P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.
Louisiana, New Orleans, 70130	Robert F. Evans (o) and Gayle A. Oglesby (c) (504 527-6543).	301 Gateway Bldg., 124 Camp St.
Lafayette, 70501	George Kinsel (o) (318 232-0239)	301 Federal Bldg.
Montana, Billings, 59103	A. F. Czarnowsky (m) and Hillary A. Oden (o) (406 245-6711, ext. 6368).	P.O. Box 2250; 217 Federal Bldg.
Great Falls, 59401	Andrew F. Bateman (c) (406 761-3314), John A. Fraher (o) (406 761-3336).	P.O. Boxes 1215 and 2265; 510 First Ave.
New Mexico, Artesia, 88210	James A. Knauf (o) (505 746-4841)	Drawer U; 210 Carper Bldg., 105 S. 4th St
Carlsbad, 88220	Robert S. Fulton (m) and Bruno R. Alto (c) (505 885-6454).	P.O. Box 1716; Federal Bldg., Fox and Haleguena Sts.
Farmington, 87401	Phillip T. McGrath (o) and J. E. Fassett (c) (505 325-4572).	P.O. Box 959; 409 Petroleum Club Plaza, 3535 East 30th St.
Hobbs, 88240	Arthur R. Brown (o) (505 393-3612)	Box 1157; 205 N. Linam St.
Roswell, 88201	J. A. Anderson (o) 505 622-9857), Donald M. Van Sickle (c) (505 622-1332).	Drawer 1857; Federal Bldg., Richardson Ave., at 5th St.

*See footnote on next page.

Location	Official in charge* and telephone number	Address
Oklahoma, Holdenville, 74848	Gerhardt H. W. Schuster (o) (405 379-3840).	P.O. Box 789; 5 Federal Bldg.
McAlester, 74502	A. M. Dinsmore (m) (918 423-5030)	509 S. 3d St.
Miami, 74354	Donal F. Ziehl (m) (918 542-9481)	P.O. Box 509; 205 Federal Bldg.
Oklahoma City, 73102	Charley W. Nease (o) (405 236-2311)	4321 Federal Court House and Office Bldg., 220 N.W. 4th St.
Tulsa, 74103	Edward L. Johnson (c) and N. Orvis Frederick (o) (918 584-7161).	4562 New Federal Bldg., 333 W. 4th St.
Oregon, Portland, 97208	Loyd L. Young (w) (503 234-3996)	P.O. Box 3202; 830 N.E. Holladay St.
Utah, Salt Lake City, 84111	Ernest Blessing (m) (801 524-5646), Rodney A. Smith (o) (801 524-5650).	8402, 8422, and 8416 Federal Bldg.; 125 S. State St.
Washington, Tacoma, 98401	Gordon C. Giles (w) (206 383-5380)	P.O. Box 1152; 244 Federal Bldg.
Wyoming, Casper, 82601	J. R. Schwabrow (o) (307 265-4310), Harry McAndrews (c) (307 265-3270).	P.O. Box 400; 305 Federal Bldg.
Newcastle, 82701	Glenn E. Worden (o) (307 746-4554)	P.O. Box 219; 611 S. Summit St.
Rock Springs, 82901	John Duletsky (o) (307 362-6422), Arne A. Mattila (m) (307 362-7350).	P.O. Box 1170; 201 and 204 First Security Bank Bldg., 502 S. Front St.
Thermopolis, 82443	Charles P. Clifford (o) (307 864-3477)	P.O. Box 590; 202 Federal Bldg.

*The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification.

GEOLOGIC DIVISION

Location	Official in charge and telephone number	Address
Alaska, College, 99735	Robert M. Chapman (479-7245)	P.O. Box 580; Brooks Memorial Bldg.
Arizona, Flagstaff, 86002	Eugene M. Shoemaker (602 774-5081)	P.O. Box 1906; 601 E. Cedar Ave.
Hawaii, Hawaii National Park, 96718	Howard A. Powers (678-485)	Hawaiian Volcano Observatory.
Kansas, Lawrence, 66045	Windsor L. Adkison (913 843-2700)	c/o State Geological Survey, Lindley Hall, Univ. of Kansas.
Kentucky, Lexington, 40503	Paul W. Richards (606 252-2312, ext. 2552)	496 Southland Drive.
Maryland, Beltsville, 20705	Dwight L. Schmidt (301 474-4800, ext. 470)	U.S. Geological Survey Bldg., Dept. of Agriculture Research Center.
Massachusetts, Boston, 02116	Lincoln R. Page (617 536-1444)	Room 1, 270 Dartmouth St.
Michigan, Marquette, 49855	Jacob E. Gair (906 226-2110)	P.O. Box 596; Industrial Lane.
New Mexico, Albuquerque, 87106	Charles B. Read (505 247-0311, ext. 483)	P.O. Box 4083, Station A; Geology Bldg., Univ. of New Mexico.
Ohio, Columbus, 43210	James M. Schopf (614 294-1810)	Orton Hall, Ohio State Univ., 155 S. Oval Drive.
Puerto Rico, Roosevelt, 00929	Reginald P. Briggs (Hata Rey 766-5340)	P.O. Box 803.
Tennessee, Knoxville, 37902	Robert A. Laurence (615 524-4011, ext. 4261).	11 Post Office Bldg.
Texas, Austin, 78701	D. Hoye Eargle (512 476-6580)	801 Federal Center.
Utah, Salt Lake City, 84111	Lowell S. Hilpert (801 524-5640)	8426 Federal Bldg.
Washington, Spokane, 99204	Albert E. Weissenborn (509 838-3121)	South 157 Howard St.
Wisconsin, Madison, 53706	Carl E. Dutton (608 255-3311, ext. 2128)	222 Science Hall, Univ. of Wisconsin.
Wyoming, Laramie, 82071	J. David Love (307 FRanklin 5-4495)	Box 3007 Univ. Station; Geology Hall. Univ. of Wyoming.

TOPOGRAPHIC DIVISION

Location	Engineer in charge and telephone number	Address
California, Menlo Park, 94025	Roy F. Thurston (415 325-2411)	345 Middlefield Rd.
Colorado, Denver, 80225	Roland H. Moore (303 233-8548)	Building 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 (703 521-5600, ext. 6555).	1109 N. Highland St.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Atlantic Coast Region: Arlington, Virginia, 22209	George E. Ferguson, Regional Hydrologist (202 343-8841).	George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Mid-Continent Region: St. Louis, Missouri, 63103	Harry D. Wilson, Jr., Regional Hydrologist (314 622-4361).	1252 Federal Bldg., 1520 Market St.
Rocky Mountain Region: Denver, Colorado, 80225	Thad G. McLaughlin, Regional Hydrologist (303 233-6701).	Bldg. 25, Federal Center.
Pacific Coast Region: Menlo Park, California, 94025	Warren W. Hastings, Regional Hydrologist (415 325-6761, ext. 337, 338, 339).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa, 35486	William L. Broadhurst (205 752-8105)	P.O. Box V; Oil and Gas Board Bldg., University of Alabama.
Alaska, Anchorage, 99501	Harry Hulsing (907 277-5526, 5527)	P.O. Box 2480; 316 Skyline Bldg., Second and E Sts.
Arizona, Tucson, 85717	Horace M. Babcock (602 792-6391, 6392, 6393, 6394).	P.O. Box 4070; Rm. 134, Geology Bldg., Univ. of Arizona Campus.
Arkansas, Little Rock, 72201	Richard T. Sniegocki (501 372-4361, ext. 5706, 5219).	2301 Federal Office Bldg., 700 W. Capitol Ave.
California, Menlo Park. 94025	R. Stanley Lord (415 325-6761, ext. 326, 327, 465, 466).	345 Middlefield Rd.
Colorado, Denver, 80225	Edward L. Moulder (303 233-3611, ext. 6444).	Bldg. 25, Federal Center.
Connecticut, Hartford, 06101	John Horton (203 244-2528)	P.O. Box 715; Rm. 235, 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 (904 224-1202)	P.O. Box 2315; Gunter Bldg., Tennessee and Woodward Sts.
Georgia, Atlanta, 30323	Albert N. Cameron (404 526-5663, 5664)	Rm. 164, Peachtree Seventh Bldg.
Hawaii, Honolulu, 96814	Mearle M. Miller (588-692, 693)	Rm. 330, First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise, 83702	Willis L. Burnham (208 342-2711, ext. 538)	Rm. 215, 914 Jefferson St.
Illinois, Champaign, 61820	William D. Mitchell (217 356-5221)	605 S. Neil St.
Indiana, Indianapolis, 46204	Malcom D. Hale (317 633-7398)	Rm. 516, 611 N. Park Ave.
Iowa, Iowa City, 52240	Sulo W. Wiitala (319 338-0581, ext. 475)	508 Hydraulic Laboratory.
Kansas, Lawrence, 66044	Robert J. Dingman (913 864-3001, 3002)	110 Linley Hall, c/o Univ. of Kansas.
Kentucky, Louisville, 40202	Floyd F. Schrader (502 582-5241, 5242, 5243).	Rm. 310, Center Bldg., 522 W. Jefferson St.
Louisiana, Baton Rouge, 70806	Rex R. Meyer (504 348-4281)	215 Prudential Bldg., 6554 Florida Blvd.
Maine, Augusta, 04330	Gordon S. Hayes (207 623-4511, ext. 708)	Vickery Hill Bldg., Court St.
Maryland, Towson, 21204	W. F. White, Jr. (301 828-7460)	724 York Rd.
Massachusetts, Boston, 02203	Charles E. Knox (617 223-2822)	2300 John Fitzgerald Kennedy Federal Bldg.
Michigan, Lansing, 48933	Arlington D. Ash (517 372-1910, ext. 561)	Rm. 700, Captiol Savings and Loan Bldg.
Minnesota, St. Paul, 55101	Charles R. Collier (612 228-7843, 7842)	Rm. 1002, New Post Office Bldg.
Mississippi, Jackson, 39205	William H. Robinson (601 948-7821, ext. 326).	P.O. Box 2052; 302 U.S. Post Office Bldg.
Missouri, Rolla, 65401	Anthony Homyk, Jr. (314 364-1599)	P.O. Box 340; 103 W. 10th St.
Montana, Helena, 59601	Charles W. Lane (406 442-3263)	P.O. Box 1696; Federal Bldg.
Nebraska, Lincoln, 68508	Kenneth A. MacKichan (402 475-3643)	127 Nebraska Hall, 901 N. 17th St.
Nevada, Carson City, 89701	George F. Worts, Jr. (702 882-1388)	222 E. Washington St.

Location	*Official in charge* and telephone number*	*Address*
New Hampshire	*See* Massachusetts District Office	*See* Massachusetts District Office.
New Jersey, Trenton, 08607	John E. McCall (609 599–3511, ext. 214)	P.O. Box 1238; Rm. 420, Federal Bldg.
New Mexico, Albuquerque, 87106	William E. Hale (505 247–0311, ext. 2246)	P.O. Box 4217; Geology Bldg., Univ. of New Mexico.
New York, Albany, 12201	Garald G. Parker (518 472–3107)	P.O. Box 948; Rm. 341, Federal Bldg.
North Carolina, Raleigh, 27602	Ralph C. Heath (919 828–9031, ext. 156, 157).	P.O. Box 2857.
North Dakota, Bismarck, 58502	Harlan M. Erskine (701 255–4227)	P.O. Box 778; Rm. 348, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus, 43212	John J. Molloy (614 469–5553, 5554)	975 W. Third Ave.
Oklahoma, Oklahoma City, 73102	John W. Odell (405 236–2311, ext. 257, 258).	4301 Federal Bldg. and U.S. Court House, 200 N.W. 4th St.
Oregon, Portland, 97208	Stanley F. Kapustka (503 234–3361, ext. 1976, 1977, 1978).	P.O. Box 3202; 803 N.E. Holladay St.
Pennsylvania, Philadelphia, 19106	Norman H. Beamer (215 597–7366)	607 U.S. Custom House, 2d and Chestnut Sts.
Puerto Rico, Hato Rey, 00918	Dean B. Bogart (809 766–3310, 3311, 3315)	12 Arroyo St.
Rhode Island	*See* Massachusetts District Office	*See* Massachusetts District Office.
South Carolina, Columbia, 29204	John S. Stallings, Acting Chief (803 252–3751).	2346 Two Notch Rd.
South Dakota, Huron, 57350	John E. Powell (605 352–8651, ext. 293, 294).	P.O. Box 1412; 231 Federal Bldg.
Tennessee, Nashville, 37203	Edward J. Kennedy (615 242–8321, ext. 5424).	Rm. 144, Federal Bldg.
Texas, Austin, 78701	Trigg Twichell (512 476–6551, 6561, 6566, 6571).	Federal Bldg., 300 E. 8th St.
Utah, Salt Lake City, 84111	Theodore Arnow (801 524–5663)	8002 Federal Bldg., 125 S. State St.
Vermont	*See* Massachusetts District Office	*See* Massachusetts District Office.
Virginia, Richmond, 23220	James W. Gambrell (703 649–3611)	200 W. Grace St.
Washington, Tacoma, 98402	Leslie B. Laird (206 383–2861, ext. 384)	Rm. 300, 1305 Tacoma Ave. S.
West Virginia, Charleston, 25301	William C. Griffin (304 343–6181, ext. 310, 311).	3303 New Federal Bldg. and U.S. Court House; 500 Quarrier St. E.
Wisconsin, Madison, 53706	Charles L. R. Holt, Jr. (608 262–2488)	1815 University Ave., Rm. 200.
Wyoming, Cheyenne, 82001	Leon A. Wiard (307 778–2317, 2414, 2331, 2474).	P.O. Box 2087; 2d Floor, Blue Cross Bldg., 215 E. Eighth Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Official in charge*	*Address*
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/Bogotá, U.S. Dept. of State, Washington, D.C. 20521, STOP 27.
Medellin	Tomas Feininger	U.S. Geological Survey, c/o American Consulate, Medellin, Colombia.
India, New Delhi	David F. Davidson	U.S. Geological Survey, c/o American Embassy, New Delhi, India.
Liberia, Monrovia	Warren L. Coonrad	U.S. Geological Survey, U.S. AID/Monrovia, U.S. Dept. of State, Washington, D.C. 20521, STOP 27.
Pakistan, Lahore	Darwin Rossman	U.S. Geological Survey, U.S. AID/Box L, APO New York 09271.
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 APO New York 09668.
Brazil, Recife	Stuart L. Schoff	U.S. Geological Survey, American Con-Gen/Recife APO New York 09676.
Rio de Janeiro	Glennon N. Mesnier Carl L. Lawrence	U.S. Geological Survey, U.S. AID/Rio de Janeiro/ENRO/USGE APO New York 09676.
Korea, Seoul	Joseph T. Callahan	U.S. Geological Survey, U.S. AID c/o American Embassy.
Nepal, Katmandu	Woodrow W. Evett	U.S. Geological Survey, U.S. AID c/o American Embassy.
Nigeria, Enugu	Elizardo Lucero	U.S. Geological Survey, U.S. AID c/o American Consulate.
Kaduna	Raymond Kiser	U.S. Geological Survey, U.S. AID c/o American Consulate.
Kano	Billy Colson	U.S. Geological Survey, U.S. AID/Lagos U.S. Dept. of State Washington, D.C. 20521.
Maiduguri	Gordon Tibbitts	U.S. Geological Survey, c/o Geological Survey of Nigeria, Maiduguri, Northern Nigeria Region.
Pakistan, Lahore	Glenn Malmberg	U.S. Geological Survey, U.S. AID/Box L APO New York 09271.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC, WATER RESOURCES, AND CONSERVATION DIVISIONS

Investigations in progress at the end of fiscal year 1967 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. A223, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C. 20242. The lowercase letter following the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (for example, 1:62,500; 1:24,000).

Abstracts. See Bibliographies and abstracts.

Analytical chemistry:
- Analytical methods—water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (I. May, W; L. F. Rader, Jr., D)
- 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, 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)
- Radiometric methods of analysis (L. L. Thatcher, w, D)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapiro, W)
- Testing for phenols in water (P. W. Anderson, w, Trenton, N.J.)
- Trace analysis methods:
  - Development (H. W. Lakin, D)
  - Research (F. N. Ward, D)
- Trace analysis service (K. W. Keong, D)
- See also Spectroscopy.

Artificial recharge:
- Idaho, Snake Plain aquifer (R. F. Norvitch, w, Boise)
- New York, treated sewage through an injection well, Bay Park, Long Island (C. N. Durfor, w, Mineola)
- Texas, Hueco bolson area (E. R. Leggat, w, Austin)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)

Asbestos--Continued
- Arizona, Blue House and McFadden Peak quadrangles (A. F. Shride, D)

Barite:
- Arkansas (D. A. Brobst, D)

Base metals:
- Colorado, Wet Mountains (M. R. Brock, D)
- Missouri, iron (P. W. Guild, W)
- See also base-metal names.

Beryllium:
- Colorado, Lake George district (C. C. Hawley, 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, bibliography (J. W. Clarke, W)
- Specific yield of ground water, California, annotated bibliography (A. I. Johnson, w, D)
- Vanadium, geology and resources, bibliography (J. P. Ohl, D)

Borates:
- Borate marshes, California, Nevada, and Oregon (W. C. Smith, M)
- California:
  - Furnace Creek area (J. F. McAllister, M)
  - Searles Lake area (G. I. Smith, M)

Chromite. See Ferro-alloy metals.

Clay-water relations:
- Clays, liquid movement in (H. W. Olsen, w, W)

Clays:
- Clay chemistry (Dorothy Carroll, M)
- Appalachia, northern part (J. W. Hosterman, W)

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Clays--Continued
- Florida and Georgia, Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, W)
- Idaho, Greenacres quadrangle (P. L. Weis, W)
- Washington, Greenacres quadrangle (P. L. Weis, W)

Coal:
- Resources of the United States (P. Averitt, D)
- Alaska:
  - Bering River coal field (A. A. Wanek, c, Anchorage)
  - Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
  - Nenana (C. Wahrhaftig, M)
- Arizona:
  - Cummings Mesa quadrangle (F. Peterson, c, D)
  - Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
- Arkansas:
  - Arkansas Basin (B. R. Haley, D)
  - Ft. Smith district (T. A. Hendricks, D)
- California:
  - Hernandez Valley quadrangle (E. E. Richardson, c, Bakersfield)
  - Priest Valley SE quadrangle (E. E. Richardson, c, Bakersfield)
- Colorado:
  - Banty Point quadrangle (H. L. Cullins, c, D)
  - Carbondale coal field (J. R. Donnell, D)
  - Chair Mountain quadrangle (L. H. Godwin, c, D)
  - Corral Bluffs quadrangle (P. E. Soister, c, D)
  - Elk Springs quadrangle (J. R. Dyni, c, D)
  - Hanover NW quadrangle (P. E. Soister, c, D)
  - Kremmling quadrangle (G. A. Izett, c, D)
  - Mellen Hill quadrangle (H. L. Cullins, c, D)
  - Montrose 1 SE, 1 SW, and 4 NE quadrangles (R. G. Dickinson, c, D)
  - Peoria quadrangle (P. E. Soister, c, D)
  - Rangely 7½-minute quadrangle (H. L. Cullins, c, D)
  - Rangely NE quadrangle (H. L. Cullins, c, D)
- Idaho, Driggs SE quadrangle (M. L. Schroeder, c, D)
- Montana:
  - Black John Coulee quadrangle (H. J. Hyden, c, D)
  - Gardiner SW quadrangle (G. D. Fraser, c, D)
  - Hardy quadrangle (K. S. Soward, c, Great Falls)
  - Jordan 2 NE quadrangle (G. D. Mowat, c, Great Falls)
  - Jordan 2 SE quadrangle (H. J. Hyden, c, D)
  - Livingston Trail Creek (A. E. Roberts, D)
  - Rocky Reef quadrangle (K. S. Soward, c, Great Falls)
- Nevada, Coaldale area (L. H. Godwin, c, Los Angeles, Calif.)
- New Mexico:
  - Fruitland Formation (J. E. Fassett, c, Farmington)
  - Gallup West area (J. E. Fassett, c, Farmington)
  - Manuelito quadrangle (J. E. Fassett, c, Farmington)
  - Raton coal basin:
    - Eastern part (G. H. Dixon, D)
    - Western part (C. L. Pillmore, D)
  - Samson Lake quadrangle (J. E. Fassett, c, Farmington)
  - San Juan Basin, east side (C. H. Dane, W)
  - Twin Butte quadrangle (J. E. Fassett, c, Farmington)
- North Dakota:
  - Clark Butte 15-minute quadrangle (G. D. Mowat, c, Great Falls, Mont.)
  - Dengate quadrangle (C. S. V. Barclay, c, D)
  - Glen Ullin quadrangle (C. S. V. Barclay, c, D)

Coal--Continued
- North Dakota--Continued
  - Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
  - North Almont quadrangle (H. L. Smith, c, D)
  - White Butte NE, NW, W, and E quadrangles (K. S. Soward, c, Great Falls, Mont.)
- Oklahoma, Ft. Smith district (T. A. Hendricks, D)
- Oregon:
  - Bandon SE quadrangle (R. G. Wayland, c, W)
  - Coquille SW quadrangle (R. G. Wayland, c, W)
- Pennsylvania:
  - Anthracite region, flood control (M. J. Bergin, W)
  - Claysville-Avella area (S. P. Schweinfurth, D)
  - Mather-Garards Fort area (B. H. Kent, D)
  - Southern anthracite field (G. H. Wood, Jr., W)
  - Waynesburg-Oak Forest area (J. B. Roen, W)
  - Western Middle anthracite field (H. Arndt, W)
- Utah:
  - Canaan Creek quadrangle (H. D. Zeller, c, D)
  - Carcass Canyon quadrangle (H. D. Zeller, c, D)
  - Cummings Mesa quadrangle (F. Peterson, c, D)
  - Dave Canyon quadrangle (H. D. Zeller, c, D)
  - Death Ridge quadrangle (H. D. Zeller, c, D)
  - Gilbert Peak 1 NE quadrangle (J. F. Dyni, c, D)
  - Griffin Point quadrangle (W. E. Bowers, c, D)
  - Horse Flat quadrangle (H. D. Zeller, c, D)
  - Jessen Butte quadrangle (J. R. Dyni, c, D)
  - Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
  - Phil Pico Mountain quadrangle (J. R. Dyni, c, D)
  - Pine Lake quadrangle (W. E. Bowers, c, D)
  - Seep Flat quadrangle (H. D. Zeller c, D)
  - Upper Valley quadrangle (W. E. Bowers, c, D)
  - Wide Hollow Reservoir quadrangle (E. V. Stephens, c, D)
- Virginia:
  - Big Stone Gap district (R. L. Miller, W)
  - Pocahontas coal beds (K. J. Englund, W)
- Wyoming:
  - Buck Creek quadrangle (W. L. Rohrer, c, D)
  - Ferris quadrangle (R. L. Rioux, c, W)
  - Ferry Peak quadrangle (D. A. Jobin c, D)
  - Fish Lake quadrangle (W. L. Rohrer, c, D)
  - Jackson quadrangle (H. F. Albee, c, D.)
  - Munger Mountain (H. F. Albee, c, D)
  - Observation Peak quadrangle (H. F. Albee, c, D)
  - Oil Mountain quadrangle (W. H. Laraway, c, Casper)
  - Pilot Knob quadrangle (W. L. Rohrer, c, D)
  - Poison Spider quadrangle (W. H. Laraway, c, Casper)
  - Reid Canyon (W. H. Laraway, c, Casper)
  - Square Top Butte quadrangle (W. H. Laraway, c, Casper)
  - Taylor Mountain quadrangle (M. L. Schroeder, c, D)
  - Teton Pass quadrangle (M. L. Schroeder, c, D)
  - Turquoise Lake (M. L. Schroeder, c, D)
  - White Rock Canyon quadrangle (H. J. Hyden, c, D)

Construction and terrain problems:
- Acid mine-water pollution control, Pennsylvania (M. J. Bergin, W)
- Austere airfield site studies, worldwide (W. E. Davies, Arlington, Va.)
- Cloud Gap, Arizona-Nevada (R. E. Davis, D)
- Deformation research (S. P. Kanizay, D)
- Foreign playas (D. B. Krinsley, Arlington, Va.)

Evapotranspiration--Continued
- Use of water by saltcedar in evapotranspirometers (T. E. A. van Hylckama, w, Buckeye, Ariz.)
- Arizona:
  - 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 (O. M. Grosz, w, Yuma, Ariz.)
- New Jersey, interception and evapotranspiration of a forest-floor shrub layer (E. C. Rhodehamel, W. A. Reiners, w, 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)
  - Investigation of missile impact craters at White Sands, N. Mex. (H. J. Moore II, M)
  - Shock phase studies (D. J. Milton, M)
  - Sierra Madera, Tex., crater studies (H. G. Wilshire, D)
- Experimental studies:
  - Apollo applications program, surveying and navigation (G. A. Swann, Flagstaff, Ariz.)
  - Apollo seismic experiment (M. F. Kane, Flagstaff, Ariz.)
  - Apollo site studies:
    - Experimental photoinvestigations (R. L. Wildey, Flagstaff, Ariz.)
    - Photogrammetry (J. D. Alderman, Flagstaff, Ariz.)
    - Terrain analysis (L. C. Rowan, Flagstaff, Ariz.)
  - Data reduction systems for Apollo application missions (G. A. Swann, Flagstaff, Ariz.)
  - Development of analytical instruments for advanced-systems missions (D. H. Dahlem, Flagstaff, Ariz.)
  - Development of geological instruments for Apollo applications missions (G. A. Swann, Flagstaff, Ariz.)
  - Development of geological instruments for early Apollo flights (J. W. M'Gonigle, Flagstaff, Ariz.)
  - Development of geological methods for advanced-systems missions (R. L. Sutton, Flagstaff, Ariz.)
  - Development of geological methods for Apollo applications missions (D. L. Schleicher, Flagstaff, Ariz.)
  - Development of geological methods for early Apollo missions (M. H. Hait, Jr., Flagstaff, Ariz.)

Extraterrestrial studies--Continued
- Experimental studies--Continued
  - Early Apollo photometry and photogrammetry (R. M. Batson, Flagstaff, Ariz.)
  - Experimental photometric investigations (H. E. Holt, Flagstaff, Ariz.)
  - Experimental photometry (H. A. Pohn, Flagstaff, Ariz.)
  - Geophysical observatory (H. L. Krivoy, Flagstaff, Ariz.)
  - Image filtering studies (R. L. Wildey, Flagstaff, Ariz.)
  - In situ field geophysics operations (R. D. Regan, Flagstaff, Ariz.)
  - In situ geologic studies (M. F. Kane, 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 (T. N. V. Karlstrom, Flagstaff, Ariz.)
  - 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 (D. E. Wilhelms, M)
  - Research in advanced geologic mapping techniques (M. R. Brock, Flagstaff, Ariz.)
  - Surveyor coordination and geologic synthesis (E. C. Morris, Flagstaff, Ariz.)
  - Surveyor photogrammetry and cartography (R. M. Batson, Flagstaff, Ariz.)
  - Surveyor photometry and photoclinometry (H. E. Holt, Flagstaff, Ariz.)
  - Theoretical photoclinometry (K. Watson, Flagstaff, Ariz.)
- Lunar mapping:
  - Lunar bibliography (J. H. Freeberg, M)
  - Cartographic investigations (H. Masursky, M)
  - Lunar Orbiter mission operations (L. C. Rowan, Flagstaff, Ariz.)
  - Lunar stratigraphy and structure (D. E. Wilhelms, M)
  - Ranger geologic mapping (N. J. Trask, Jr., M)
- Tektite and meteorite investigations:
  - Air-wave investigations (E. M. Shoemaker, Flagstaff, Ariz.)
  - Chemistry of cosmic and related materials (F. Cuttitta, W)
  - Chemistry of extraterrestrial materials (F. Cuttitta, W)
  - Investigation of cosmic dust collected from space (M. H. Carr, M)
  - Investigation of cosmic dust collected from the atmosphere (M. B. Duke, W)
  - Petrography of tektites (E. C. T. Chao, W)
  - Petrology of meteorites (P. R. Brett, W)

Ferro-alloy metals:
- Chromium resource studies (T. P. Thayer, W)
- Manganese:
  - Geology and geochemistry (D. F. Hewett, M)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Connecticut--Continued
Danielson quadrangle, bedrock geology (H. R. Dixon, Boston, Mass.)
Durham quadrangle, bedrock geology (H. E. Simpson, D)
East Killingly quadrangle, bedrock geology (G. E. Moore, Columbus, Ohio)
Eastford quadrangle, surficial geology (M. H. Pease, Boston)
Marlborough quadrangle, bedrock geology (G. L. Snyder, D)
Meriden quadrangle, bedrock geology (P. M. Hanshaw, W)
Middle Haddam quadrangle, bedrock geology (G. P. Eaton, Pasadena, Calif.)
New Hartford quadrangle, bedrock geology (R. W. Schnabel, D)
New Preston quadrangle, surficial geology (R. B. Colton, D)
Norwalk South quadrangle, surficial geology (H. E. Malde, D)
Putnam quadrangle, bedrock geology (H. R. Dixon, D)
Roxbury quadrangle, surficial geology (H. E. Malde, D)
Southwick quadrangle, surficial and bedrock geology (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, Boston, Mass.)
Tariffville quadrangle, surficial geology (A. D. Randall, w, Binghamton, N. Y.)
Tolland Center quadrangle, surficial geology (G. W. Holmes, W)
Torrington quadrangle, surficial geology (R. B. Colton, D)
Watch Hill quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Waterbury quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
West Granville quadrangle, bedrock and surficial geology (R. W. Schnabel, D)
West Springfield quadrangle, surficial geology (R. B. Colton, Boston, Mass.)
West Torrington quadrangle, surficial geology (R. W. Colton, D)
District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)
Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Georgia, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Idaho:
Aspen Range-Dry Ridge area (V. E. McKelvey, W)
Bancroft quadrangle (S. S. Oriel, D)
Bayhorse area (S. W. Hobbs, D)
Driggs NE, SE, and SW quadrangles (M. L. Schroeder, c, D)
Elmira quadrangle (J. E. Harrison, D)
Greenacres quadrangle (P. L. Weis, Spokane, Wash.)
Hawley Mountain quadrangle (W. J. Mapel, D)
Leadore quadrangle (E. T. Ruppel, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Idaho--Continued
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Patterson quadrangle (E. T. Ruppel, D)
Riggins quadrangle (W. B. Hamilton, D)
Yandell Springs quadrangle (D. E. Trimble, D)
Yellow Pine quadrangle (B. F. Leonard, D)
Ohio River Quaternary (M. C. Weiss, Columbus, Ohio)
Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Kentucky:
Note: The entire State of Kentucky is being mapped geologically by 7½ minute quadrangles under a cooperative program with the Kentucky Geological Survey. 249 quadrangles have been published, and 179 more are currently in progress. Project is under the supervision of P. W. Richards, Lexington, Ky. The following investigation is separate from the cooperative mapping program:
Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Maine:
Chain Lakes area (E. L. Boudette, W)
Kennebago Lake and Cupsuptic quadrangles (E. L. Boudette, W)
Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
The Forks quadrangle (F. C. Canney, D)
Maryland:
Cecil County (L. C. Conant, 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)
Ashfield quadrangle, surficial geology (J. H. Hartshorn, Boston)
Ashley Falls quadrangle, surficial geology (G. W. Holmes, W)
Athol quadrangle, bedrock geology (A. L. Mook, Boston)
Blandford quadrangle, bedrock and surficial geology (N. L. Hatch, Jr., W)
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)
Boston South quadrangle, bedrock geology (K. G. Bell, D)
Chatham quadrangle, surficial geology (Carl Koteff, Boston)
Chester quadrangle, bedrock and surficial geology (N. L. Hatch, Jr., W)
Concord quadrangle, bedrock geology (N. P. Cuppels, Boston)
Dennis quadrangle, surficial geology (R. N. Oldale, Boston)
Easthampton quadrangle, surficial geology (J. H. Hartshorn, Boston)
Egremont quadrangle, bedrock geology (N. M. Ratcliffe, Boston)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
New Mexico--Continued
San Andres Mountains, northern part (G. O. Bachman, D)
San Juan Basin, east side (C. H. Dane, W)
Starvation Peak area (R. B. Johnson, D)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Valles Mountains, petrology (R. L. Smith, W)
New York:
Taconic sequence (E-an Zen, W)
Dannemora quadrangle, surficial geology (C. S. Denny, W)
Gouverneur area, metamorphism and origin of mineral deposits (A. E. J. Engel, La Jolla, Calif.)
Plattsburgh quadrangle, surficial geology (C. S. Denny, W)
Pope Mills and Natural Dam quadrangles, New York (C. E. Brown, W)
North Carolina:
Central Piedmont (H. Sundelius, W)
Morganton area, geomorphic studies (J. T. Hack, W)
Northern Slate Belt, North Carolina-Virginia (Lynn Glover, O. T. Tobisch, W)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Great Falls, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
North Almont quadrangle (H. L. Smith, c, D)
White Butte NE, NW, W, and E quadrangles (K. S. Soward, c, Great Falls, Mont.)
Oklahoma, Ft. Smith district (T. A. Hendricks, D)
Oregon:
Bandon SE quadrangle (R. G. Wayland, c, W)
Coquille SW quadrangle (R. G. Wayland, c, W)
Loomis quadrangle (C. D. Rinehart, M)
Monument quadrangle (R. E. Wilcox, D)
Newport Embayment (P. D. Snavely, Jr., M)
Pennsylvania:
Anthracite region, flood control (M. J. Bergin, W)
Devonian stratigraphy of State (G. W. Colton, W)
Allenton 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)
Shenango quadrangle, Mercer County (G. R. Schiner, w, Harrisburg)
Southern anthracite field (G. H. Wood, Jr., W)
Stoneboro quadrangle, Mercer County (G. R. Schiner, w, 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)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Rhode Island:
Avon quadrangle, bedrock geology (R. W. Schnabel, D)
Bashbish Falls quadrangle, surficial geology (G. W. Holmes, W)
Bristol quadrangle, surficial geology (H. E. Simpson, D)
Broad Brook quadrangle, surficial geology (R. B. Colton, D)
Clayville quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Collinsville quadrangle, surficial geology (R. B. Colton, D)
Durham quadrangle, surficial geology (H. E. Simpson, D)
East Killingly quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Eastford quadrangle, bedrock geology (M. H. Pease, J. D. Peper, Boston, Mass.)
Ellington quadrangle, surficial geology (R. B. Colton, D)
Fitchville quadrangle, bedrock geology (G. L. Snyder, D)
Hampden quadrangle, surficial geology (R. B. Colton, D)
Hampton quadrangle, bedrock geology (H. R. Dixon, D)
Manchester quadrangle, surficial geology (R. B. Colton, D)
New Britain quadrangle:
Bedrock geology (H. E. Simpson, D)
Surficial geology (H. E. Simpson, D)
New Hartford quadrangle, surficial geology (R. W. Schnabel, D)
Newport quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Norwich quadrangle, bedrock geology (G. L. Snyder, D)
Plainfield quadrangle, bedrock geology (H. R. Dixon, D)
Prudence Island quadrangle, bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Scotland quadrangle, bedrock geology (H. R. Dixon, D)
Sharon quadrangle, surficial geology (G. W. Holmes, W)
South Canaan quadrangle, surficial geology (G. W. Holmes, W)
South Sandisfield quadrangle, surficial geology (G. W. Holmes, W)
Tariffville quadrangle, bedrock geology (R. W. Schnabel, D)
Watch Hill quadrangle, surficial geology (J. P. Schafer, Boston, Mass.)
West Springfield quadrangle, surficial geology (J. H. Hartshorn, Boston, Mass.)
Westford quadrangle:
Bedrock geology (M. H. Pease, J. D. Peper, Boston, Mass.)
Surficial geology (M. H. Pease, J. D. Peper, Boston, Mass.)

Geologic mapping--Continued
- Map scale 1 inch to 1 mile, and larger--Continued
  - Rhode Island--Continued
    - Willimantic quadrangle, bedrock geology (G. L. Snyder, D)
    - Windsor Locks quadrangle:
      - Bedrock geology (R. W. Schnabel, D)
      - Surficial geology (R. B. Colton, D)
  - South Dakota:
    - 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)
    - Midway belt, western part of State (W. S. Parkes, w, Nashville)
  - Texas:
    - Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
    - North-central part, Pennsylvanian Fusulinidae (D. A. Myers, D)
  - Utah:
    - Bingham Canyon district (E. W. Tooker, M)
    - Canaan Creek quadrangle (H. D. Zeller, c, D)
    - Carcass Canyon quadrangle (H. D. Zeller, c, D)
    - Causey Dam quadrangle (T. E. Mullens, c, D)
    - Coal-mine bumps (F. W. Osterwald, D)
    - Confusion Range (R. K. Hose, M)
    - Crawford Mountains (W. C. Gere, c, D)
    - Cummings Mesa quadrangle (F. Peterson, c, D)
    - Dave Canyon quadrangle (H. D. Zeller, c, D)
    - Death Ridge quadrangle (H. D. Zeller, c, D)
    - Gilbert Peak 1 NE quadrangle (J. R. Dyni, c, D)
    - Griffin Point quadrangle (W. E. Bowers, c, D)
    - Horse Flat quadrangle (H. D. Zeller, c, D)
    - Jessen Butte quadrangle (J. R. Dyni, c, D)
    - Lehi quadrangle (M. D. Crittenden, Jr., M)
    - Morgan quadrangle (T. E. Mullens, c, D)
    - Navajo Reservation (R. B. O'Sullivan, D)
    - Oak City area (D. J. Varnes, D)
    - Ogden 4 NE quadrangle (T. E. Mullens, c, D)
    - Ogden 4 NW quadrangle (R. J. Hite, D)
    - Park City area (M. D. Crittenden, Jr., M)
    - Phil Pico Mountain quadrangle (J. R. Dyni, c, D)
    - Pine Lake quadrangle (W. E. Bowers, c, D)
    - Promontory Point (R. B. Morrison, D)
    - Salt Lake City and vicinity (R. Van Horn, D)
    - Seep Flat quadrangle (H. D. Zeller, c, D)
    - Sheeprock Mountains, West Tintic district (H. T. Morris, M)
    - Upper Valley quadrangle (W. E. Bowers, c, D)
    - Vernal phosphate area (E. M. Schell, c, D)
    - Wide Hollow Reservoir quadrangle (E. V. Stephens, c, D)
    - Buck Creek quadrangle (W. L. Rohrer, c, D)
  - Vermont:
    - Heath quadrangle (N. L. Hatch, Jr., Boston, Mass.)
    - Rowe quadrangle (N. L. Hatch, Jr., Boston, Mass.)
  - Virginia:
    - Appalachian folded belt, southern part (L. D. Harris, W)
    - Big Stone Gap district (R. L. Miller, W)
    - Northern Slate Belt, North Carolina-Virginia (Lynn Glover, O. T. Tobisch, W)
    - Quantico quadrangle (D. L. Southwick, W)

Geologic mapping--Continued
- Map scale 1 inch to 1 mile, and larger--Continued
  - Virginia--Continued
    - Washington, D. C., metropolitan area, (H. W. Coulter, C. F. Withington, W)
  - Washington:
    - Chewelah No. 4 quadrangle (F. K. Miller, M)
    - Glacier Peak quadrangle (D. F. Crowder, M)
    - Grays River quadrangle (E. W. Wolfe, M)
    - Inchelium quadrangle (A. B. Campbell, D)
    - Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
    - Olympic Peninsula, eastern part (W. M. Cady, D)
    - Puget Sound Basin (H. H. Waldron, D)
    - Stevens County (R. G. Yates, M)
    - Togo Mountain quadrangle (R. C. Pearson, D)
    - Twin Lakes quadrangle (G. E. Becraft, D)
  - Wyoming:
    - Beartooth Butte quadrangle (W. G. Pierce, M)
    - Clark Fork quadrangle (W. G. Pierce, M)
    - Cokeville quadrangle (W. W. Rubey, Los Angeles, Calif.)
    - Deep Lake quadrangle (W. G. Pierce, M)
    - Devil Slide quadrangle (E. K. Maughan, D)
    - Devils Tooth quadrangle (W. G. Pierce, M)
    - Ferris quadrangle (R. L. Rioux, c, W)
    - Ferry Peak quadrangle (D. A. Jobin, c, D)
    - Fish Lake quadrangle (W. L. Rohrer, c, D)
    - Grand Teton National Park (J. D. Love, Laramie)
    - Hulett Creek (C. H. Maxwell, D)
    - Jackson quadrangle (H. F. Albee, c, D)
    - LaBarge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)
    - Munger Mountain (H. F. Albee, c, D)
    - Observation Peak quadrangle (H. F. Albee, c, D)
    - Oil Mountain quadrangle (W. H. Laraway, c, Casper)
    - Pilot Knob quadrangle (W. L. Rohrer, c, D)
    - Poison Spider quadrangle (W. H. Laraway, c, Casper)
    - Reid Canyon quadrangle (W. H. Laraway, c, Casper)
    - Spence-Kane area (R. L. Rioux, c, W)
    - Square Top Butte quadrangle (W. H. Laraway, c, Casper)
    - Sweetwater County, Green River Formation (W. C. Culbertson, D)
    - Taylor Mountain quadrangle (M. L. Schroeder, c, D)
    - Teton Pass quadrangle (M. L. Schroeder, c, D)
    - Turquoise Lake (M. L. Schroeder, c, D)
    - Wapiti quadrangle (W. G. Pierce, M)
    - White Rock Canyon quadrangle (H. J. Hyden, c, D)
    - Wind River Basin, regional stratigraphy (W. R. Keefer, Laramie)
    - Wind River Mountains, Quaternary geology (G. M. Richmond, D)
    - Yellowstone National Park:
      - Pre-Tertiary rocks:
        - Northern part (E. T. Ruppel, D)
        - South-central part (W. R. Keefer, D)

Geomorphology:
- Geomorphology and hydrology, basic research (C. W. Carlston, w, W)
- Hillslope erosion (S. A. Schumm, w, D)
- Mathematical geomorphology (A. E. Scheidegger, w, Urbana, Ill.)

Geomorphology--Continued
Mudflow studies (D. R. Crandell, D)
Relation of drainage networks and basin development to rock type and climate (R. F. Hadley, w, D)
Sediment effects on fluvial morphology (S. A. Schumm, w, D)
Stream morphology and processes (R. K. Fahnstock, w, D)
Colorado River, geologic history (C. B. Hunt, w, Baltimore, Md.)
Ohio River valley, geologic development (L. L. Ray, W)
Arizona, process, landform, and vegetation in a semiarid area: The San Pedro Valley (R. C. Zimmerman, w, Johns Hopkins Univ., Baltimore, Md.)
California:
Alluvial fans and pediments (L. K. Lustig, w, Tucson, Ariz.)
Channel morphology of San Francisquito Creek (J. R. Crippen, w, M)
Effect of diversion works on the Trinity River (K. M. Scott, w, Sacramento)
Northwestern California streambed changes (J. J. Hickey, w, M)
Rates of land denudation (V. C. La Marche, Jr., w, M)
Sierra Nevada, geomorphic studies (R. J. Janda, w, M)
Indiana:
Channel-meander studies (J. F. Daniel, w, Indianapolis)
Ohio River Quaternary (M. C. Weiss, Columbus, Ohio)
Maryland, Potomac River, geomorphic aspects of the Sisters and Watts Branches (L. B. Leopold, w, W)
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PUBLICATIONS IN FISCAL YEAR 1967

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 1967 (July 1, 1966–June 30, 1967) 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 the computer compilation of the list (in the text, the first cipher of the numbers is replaced by the prefix "r"). References to this list are identified in the preceding text by author and acquisition number: for example, H. D. Ackermann (r1080).

The list also includes a number of publications that were not listed in "Geological Survey Research 1966" and earlier volumes.

Abee, H. H. *See* Pickering, R. J. 01990

Ackermann, Hans D. *See* Hassemer, Jerry H. 00722

Ackermann, Hans D. *See* Godson, R. H. 00723

01080 **Ackermann, Hans D.** Limits of head-wave amplitudes for short spreads from various charge sizes, blasting caps, and 45-kg weight drop, *in* Investigation of in situ physical properties of surface and subsurface site materials by engineering geophysical techniques—NASA Contract T-25091(G), Ann. Rept. Fiscal Year 1966: U.S. Geol. Survey, p. 41-49, illus., 1966.

01585 **Ackroyd, E. A.** Preliminary map showing the estimated potential yields of the Little Muddy aquifer, Williams County, North Dakota: U.S. Geol. Survey open-file report, 1 sheet, 1967.

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